Title: Exploring the experience of liminality in learners of secondary school physics.

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Exploring the experience of liminality in learners of secondary school physics.

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Author's declaration

I, David Appleby, declare that this thesis and the work presented in it are my own and have been generated by me as the result of my own original research.

Exploring the experience of liminality in learners of secondary school physics.

I confirm that:

This work was done wholly while in candidature for a research degree at this University;

No part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution.

Where I have cited the published work of others, this is always clearly attributed.

Where I have quoted from the work of others the source is always given. With the exception of such quotations, this thesis is entirely my own work.

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Abstract

The idea of 'threshold concepts' has attracted attention and framed many enquiries into learning, particularly in higher education, since it was first proposed by Meyer and Land in 2003. It has formed the basis of a broadly-based scholarly community; however, it lacks some of the features of the kind of generative research programmes described by Lakatos. These include the lack of an explicit ontological and epistemological position and a lack of clarity around the fundamental concepts of transformation and liminality. Instead, much of the literature on threshold concepts uses metaphors and analogies and borrows from eclectic fields and traditions. This is particularly evident in discussions of the liminality found amongst learners when confronted by troublesome knowledge or cognitive conflicts.

This empirically-based study proposes that it is possible to understand the philosophical perspectives underpinning threshold concepts in terms of a commitment to ontological realism combined with epistemological constructivism. This combination is evident elsewhere, notably in constructivist science education, in physics, and in the tension between classic Glaserian and Charmazian constructivist grounded theory.

This study therefore uses a hybridised grounded theory approach, combined with a think-aloud method, in order to study experiences of liminality among pre-university learners faced with a threshold concept in physics. Learners used reflective self-dialogue and deliberative problem—solving strategies to reconcile a mismatch in explanations. Key characteristics of liminality were identified including threshold

avoidance, two forms of stuckness, oscillation and mimicry. However, the use of grounded analysis resulted in a reinterpretation of liminality from a period during which transformative learning took place to one in which a learner actively explored the problem space; active exploratory learning emerged as a core category. This facilitated a change in perspective from teacher-centric to learner-centric, a resolution of the two forms of stuckness previously observed, and the development of a coherent narrative to explain oscillation and mimicry and to enable a resolution of the differences between the 'possible breakthrough ideas' observed during this study and the 'eureka' moments described in the literature.

This reinterpretation enables the development of a new understanding of liminality which paves the way towards the development of threshold concepts as a theory of learning. It also demands a pedagogical refocusing from the remediation or avoidance of learner deficit to strategies for enabling learners to make the most of the liminal experience.

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Chapter 1: Introduction

I have written this thesis using the first person. This is partly because I am using an interpretivist perspective. Another reason is that the conclusions I develop depend on taking a particular perspective of the liminal experience. An alternative perspective might lead to alternative conclusions. I do not argue that mine are the only possible conclusions, only that my conclusions are justified given the perspective I have taken. The use of the first person, where appropriate, is intended to emphasise this.

1.1: Personal experience leading to threshold concepts

I was a teacher at a number of English secondary schools for 33 years. Throughout that time I prepared pupils for physics A-level which is the assessment normally taken when aged eighteen which acts as a gateway to university study in physics. I soon learned that some of the topics within physics at this level posed substantial difficulties for most learners. These were the topics that frequently determined which pupils would go on to achieve top grades; somehow if the topic was understood a number of other topics suddenly seemed to make sense. These topics were generally the most difficult for me to explain. How hard a learner tried did not seem to make the difference between learners who understood immediately, or after a struggle, and those who never properly understood the concepts underpinning these topics. Some of these concepts could challenge basic notions and on the whole the

learners found them fascinating: they were enjoyable to teach and they seemed to be enjoyable to learn.

It seemed to me that many of these topics were often the same as topics that had initiated in the history of the development of physics what Kuhn (1996) called a paradigm change. This similarity had also been noticed by theorists studying learning from the perspective of concept change; for example Vosniadou and Brewer (1992, 537) had observed that ‘in some cases the ideas of novices are found to resemble earlier theories in the history of science’, giving impetus theory as an example.

I then discovered that some of the ideas that caused problems for my pupils, such as Newtonian dynamics, were identified in the literature on threshold concepts (for example, Meyer and Land 2003). Threshold concepts were often associated with knowledge that was in some way ‘troublesome’ and this explained why some topics were more difficult to teach than others; many of these topics challenged basic notions. The idea that some concepts were like ‘portals’ leading to transformed understanding of an integrated and bounded subsection of physics explained why some of my pupils found that if they could understand the ‘difficult’ topics they could access other topics as well. This also explained the ‘all or nothing’ distribution I often found when assessing pupils (and discussed by Scott *et al.* 2010); these topics discriminated between learners.

I decided I needed to learn more about threshold concepts.

1.2: Threshold concepts as a ‘body of scholarship’

1.2.1: The origin of threshold concepts

The idea of threshold concepts was introduced in a report to a ‘Research Programme Project’ concerned with ‘Enhancing Teaching-Learning Environments in Undergraduate Courses’ (Meyer and Land 2003). They identified threshold concepts through discussions with university teachers within the programmes of study at undergraduate level of various disciplines. Threshold concepts, they suggested, were to be found in the curriculum of disciplines, though they might be easier to identify in some disciplines than in others. Examples of threshold concepts included ‘opportunity cost’ in economics and ‘limit’ in mathematics. Threshold concepts, they suggested, are distinct from but ‘within’ core concepts[1]; they differentiate ‘between core learning outcomes that represent “seeing things in a new way” and those that do not.’ A threshold concept is a portal to a ‘transformed internal view’. Such a transformation is ‘probably irreversible’. As was appropriate with such a pioneering study which was intended to initiate debate and was essentially exploratory in nature they used terms such as 'likely', 'probably', ‘possibly', and 'potentially' and made a number of tentative suggestions, some implicit and some explicit. Threshold concepts have some key characteristics. They are ‘transformative’ in that they cause

[1] A definition of the word ‘concept’ in the literature is elusive. ‘The term concept is one that everybody uses and nobody explains.’ (Toulmin 1972, 8) Outside threshold concept scholarship definitions vary. Thus, for Donald (2002, 9) a concept is a ‘unit of thought or element of knowledge that allows us to organize experience’ and for Carey (2000, 14) ‘concepts are units of mental representation roughly equivalent to a single word’ but others, for example Mead and Gray (2010), point out that at least some of these units can be broken down into smaller elements. Other authorities focus on the relationship between concepts. Thus Deleuze and Guattari (1994, 79) assert that ‘a concept lacks meaning to the extent that it is not connected to other concepts’. Many (for example Walker (2013) and Kinchin *et al.* (2010)) see concepts as arranged in networks and the distinction between threshold concepts and core concepts (Meyer and Land 2003) implies a hierarchy of concepts. In this study I will presume that a concept is a potentially divisible unit of thought connected with other concepts by relationships that might be described using a network.

‘a significant shift in the perspective of a subject, or part thereof’. This may include a values or identity shift. They are ‘irreversible’: once learned they are ‘unlikely to be forgotten’. They are integrative; a threshold concept ‘exposes the previously hidden interrelatedness of something’. They may be ‘bounded’ in that they tend to define academic territories. They may be linked with various forms of troublesome knowledge. The original paper draws on the work of Perkins (1999) who describes various forms of troublesome knowledge including routine ‘ritual’ knowledge such as ‘names and dates’; ‘inert’ knowledge such as ‘words that are understood but not used actively’; ‘conceptually difficult knowledge’ which is often understood as a ‘mix of misunderstandings and ritual knowledge’; ‘alien knowledge’, for example some of the counter-intuitive ideas encountered in physics; ‘tacit knowledge’ such as the idea of equal temperament in music; and troublesome language such as words whose in-discipline specialist meanings differ from their meanings in common parlance. Finally, a learner who found it difficult to understand a threshold concept might experience ‘liminality ... a suspended state in which understanding approximates to a kind of mimicry or lack of authenticity.’ (Meyer and Land 2003).

The bibliography for Meyer and Land (2003) shows an intriguing mixture of references including post-structuralists Jacques Derrida and Michel Foucault, cognitivist Jerome Bruner, constructivist David Perkins, and social constructionist Etienne Wenger. But perhaps the strongest influence on the initial paper was that it was part of a ‘UK national research project into the possible characteristics of strong teaching and learning environments in the disciplines for undergraduate education' (Cousin 2006a). It might be argued that the perception of the need for such a research project was the expansion of the university sector in the UK from 22

universities before 1960 to nearly 90 by the end of the second millennium (and another 50 since 2001). There were fewer than a million adult students in the UK in 1991 and more than 1.3 million in 2002 and it seemed clear the number would continue to rise, as it has to more than 1.9 million in 2015. Such an increase suggested a broader spectrum of prior achievement which in turn implied that more students might require more support with their learning; hence the need for research into the undergraduate curriculum at this time.

1.2.2: Is threshold concepts a 'research programme'?

The idea of threshold concepts has proved attractive with, at the time of writing, four key texts and six international conferences and with a bibliography maintained online by Mick Flanagan which showed on 30th January 2018, 1685 papers written by 1951 authors in 53 countries. The 2003 paper itself had 1375 citations on Google Scholar (on 19th February 2018). Threshold concepts have been the focus of a special issue in the *Journal of Adult Theological Education, Education & Training* (focusing on Business Education), and the *Journal of Management Education;* the *International Journal for Practice-Based Learning* is planning a special edition on *Threshold Concepts in Health and Social Care*. Threshold concepts have achieved more traction in subjects with an extensive knowledge base rather than discursive subjects. The discipline which appears most in the key word list of the bibliography maintained by Flanagan (2017; all figures correct on 17th December 2017) is Engineering with over 100 mentions; other disciplines mentioned include Economics (34), Medicine (33), Arts (32), Maths (30), Languages (29), Biology (24), Chemistry (18), Physics (10), History (22) and Geography (14). There is a clear bias towards

higher education: ‘university’ appears 48 times in the key word list but ‘schools’ only ten times; ‘undergraduates’ 51 times and ‘pupils’ twice.

Given such popularity, can it be concluded that threshold concepts have achieved the status of what Kuhn (1996) calls a ‘paradigm’ or what Lakatos (1970) calls a ‘research programme’? There are a number of points of similarity between the threshold concepts ‘body of scholarship’ (Schwartzman (2010, 24) and the features of paradigms. For example, Kuhnian paradigms are characteristically initiated by a single text and then pursued by a group of adherents who recognise the ideas as ‘more successful than their competitors in solving a few problems that the group of practitioners has come to recognize as acute’ (Kuhn 1996, 23). This is the case with threshold concept scholarship. Paradigms contain ‘a set of received beliefs’ (Kuhn 1996, 4). In Kuhn’s later revised explanation of the paradigm as a ‘disciplinary matrix’ (issued as a postscript in 1969) he characterises these received beliefs as ‘expressions, deployed without question or dissent by group members … which function in part as laws but also in part as definitions.’ (Kuhn 1996, 182 – 183). At the core of threshold concept scholarship are the five characteristics which Meyer and Land (2003) assigned to threshold concepts (transformativity, integrativity, irreversibility, boundedness and troublesomeness); these ‘deployed without question or dissent’ by threshold concept scholars as shown by a Google Scholar search which associated all five concepts with ‘threshold concept’ in at least 78 papers in the threshold concept literature; hence justifying the description of these five characteristics as ‘received beliefs’. A paradigm has a ‘body of accepted theory[2]‘ as

[2] The use of the word ‘theory’ is potentially problematic since it is often interpreted in different ways. For example, grounded theorists distinguish between substantive theories and formal theories (Urquhart 2013, 192 – 193). As Bohm (1996, 89) points out, the Greek route of the word ‘theory’

expounded by a textbook (Kuhn 1996, 10). Four key collections of papers on threshold concepts have been produced (Meyer and Land 2006; Land *et al.* 2008; Meyer *et al.* 2010; and Land *et al.* 2016), each one having both Meyer and Land as part of the editorial team; this, I will argue below (section 1.3.1) has created a corpus of canonical ideas.

Furthermore, one aspect of Kuhn's understanding of paradigm as a disciplinary matrix is that a paradigm involves exemplars by which new entrants to the community can learn the 'group-licensed way of seeing' (Kuhn 1996, 189). It could be argued that the canonical texts fulfil this role in threshold concept scholarship.

However, Kuhn (1996, 17) states that a paradigm sets out 'intertwined theoretical and methodological belief that permits selection, evaluation, and criticism'. In Kuhn's 1969 explanation of paradigm as disciplinary matrix these intertwined beliefs correspond to 'values' which are used for making judgements; Kuhn proposes simplicity, self-consistency, plausibility, compatibility with other theories, and accuracy as values to be used in judging theories but this is because he focuses on the physical sciences. Other disciplines might have alternative values. But it is argued below (section 2.3) that the ontological and epistemological foundations of threshold concepts are problematic. For example, threshold concepts appear to have a broadly constructivist perspective but there are few explicit references to

derives from a verb that references viewing. Thus he proposes 'we might regard a theory as 'a view', or 'a form of insight', rather than as a 'well defined and certain knowledge about reality'.' I wish to avoid being entangled in a debate about whether or not, for example, threshold concepts is a theory of learning. However, Bohm has described the ends of a spectrum and this makes it possible to debate whether, for example, threshold concepts is undertheorised.

constructivism. This makes it hard to construct values that can be used to judge or evaluate ideas.

Furthermore, another component of a Kuhnian disciplinary matrix is ‘metaphysical paradigms … shared commitments to such beliefs as … supply the group with preferred or permissible analogies and metaphors’. (Kuhn 1996, 184). In my review of the literature on liminality in section 2.5 I list thirteen metaphors for liminality (it is a state, a zone, a period, a process, a tunnel, a flux etc). This suggests a looseness in this aspect of threshold concept scholarship which raises a further doubt about describing it as a Kuhnian paradigm.

It seems reasonable to conclude, therefore, that threshold concept scholarship shares many of the features of Kuhnian paradigms but not all.

There are even fewer resonances with the characteristics described by Lakatos (1970, 132) of what he calls a ‘research programme’. Lakatos criticised Kuhn for an overly psychological description of how ideas change and tried to develop a more rational account. Thus he noted that most research programmes are ‘grafted onto older programmes with which they were blatantly inconsistent’ (Lakatos 1970, 142). As I will show in section 2.4.3, threshold concept scholarship has largely ignored the pre-existing literature on concept change learning despite substantial resonances between the two sets of ideas.

Exploring links with other theories of learning is one way in which this study will attempt to develop threshold concept scholarship into a Lakatosian research programme.

In order to explain how a research programme could develop despite inconsistencies with previous work and despite the likelihood, at least in the early stages, of empirical anomalies, Lakatos (1970, 133) proposed that a research programme contained a 'hard core' of fundamental ideas. These are exempted from normal challenge; for example if evidence emerges that might undermine them this will be explained away by a 'protective belt of auxiliary hypotheses'. It could be argued that the five characteristics of threshold concept form just such a core. For example, a paper that found 'no evidence that our TCs are any more irreversible than other concepts' (Scott and Harlow 2012) made little impact being cited just 13 times by authorial teams that did not include either of the original authors. Thus, evidence against irreversibility has largely been ignored; it remains unchallenged.

However, in a Lakatosian model the auxiliary hypotheses act as protection so that the ideas in the core can be explicit, clear and unequivocal. This is not the case for threshold concepts. The five key characteristics are tentatively proposed: 'A threshold concept … *is likely to be* transformative … [is] *probably* irreversible … [is] integrative … [is] *possibly often (though not necessarily always*) bounded … [and is] *potentially (and possibly* inherently) troublesome' [my emphases] (Meyer and Land 2003). In addition, rather than being clearly defined most of the core ideas of threshold concepts are described using metaphor and anecdote; for example, irreversibility is explained using the story of the expulsion of Adam and Eve from the

Garden of Eden (Meyer and Land 2003). Furthermore, it is not just the ontology and epistemology which is implicit. Inference and interpretation must be used to construe the meaning of many of the terms. For example, it is conjectured that Meyer and Land (2003) envisage learning as transformation. The first characteristic of a threshold concept that they list is that it is transformative. They use the word 'transformed' or 'transformative' five times in the first six sentences of their introduction. They cite Mezirow who has written at length on transformative learning. Later, one of the four key collections of papers (Meyer *et al.* 2010) is called *Threshold concepts and Transformational Learning.* Other workers in the field of threshold concept scholarship (for example, Perkins 2006, 44; Quinlan *et al.* 2013; Walker 2013) regard transformativity as fundamental. The evidence thus suggests that learning-as-transformation is a fundamental concept of threshold concept scholarship but finding an explicit statement of this has proved elusive. Similarly the concept of 'liminality' seems to be central to the notion of threshold concepts. In the 2003 paper, Meyer and Land regarded liminality as 'a suspended state' where learners went when they had difficulty passing across the threshold but by Meyer and Land (2005) liminality had emerged as the period during which the transformation took place. But liminality is not well-defined; rather, it is described using examples from Greek mythology (Meyer and Land 2003) and anthropological studies of rites of passage (Meyer and Land 2005). Schwartzman (2010, 26) states that 'to date, TC scholarship ... depicts implications of journey through that [liminal] space as transformations or ontological shifts, but does not address the nature of the space or the journey' and Martindale *et al.* (2016, 248) assert that 'the experience of liminality ... is well recognised but not very well understood'. More recently Barton and James (2017, 251) have identified 'the need for further enquiry into liminality'

and liminality has been described by Land *et al.* (2016, xvii) as ‘the “black box” of thresholds research’.

Hence a second way in which this study will endeavour to develop threshold concept scholarship towards becoming a Lakatosian research programme is to make the fundamental ideas more explicit, and clearer and less equivocal.

Finally, Lakatos (1970, 132 - 137) states that a ‘genuine research programme’ contains from the beginning, at least in outline ‘methodological rules’ some of which ‘tell us what paths of research to avoid ... and others what paths to pursue’. To extrapolate from this idea, a research programme should be able to turn its tools upon itself so that it can, for example, recognise its own assumptions. Threshold concept scholarship is in the perfect position to do this. For example, it is argued below (for example in section 2.2.2) that ‘learning as transformation within liminality’ is a fundamental idea for threshold concept scholarship. Is it therefore a threshold concept for threshold concepts? Does grasping this idea irreversibly transform our understanding of threshold concepts? Is it integrative with respect to other concepts? Does it form a boundary between threshold concept scholarship and other theories of learning? This outlines a third way in which this study will attempt to evolve threshold concept scholarship towards becoming a Lakatosian research programme.

In summary, it has been argued that despite the substantial traction of the threshold concepts idea its theoretical foundation is not yet sufficiently established for a Kuhnian paradigm or a Lakatosian research programme. This study aims to develop threshold concept scholarship in three ways: to explore links with other theories of

learning; to make the fundamental ideas clearer, less equivocal, and more explicit; and to consider whether the notion of ‘learning as transformation within liminality, is a threshold concept within threshold concepts.

1.3 Contents of the thesis

1.3.1 Chapter 2 Literature Review

There is already an extensive literature on threshold concept scholarship; the review necessarily involved taking a selective sample of these papers.

It is argued above that one of the ways in which threshold concept scholarship has parallels with a Lakatosian research programme or a Kuhnian paradigm is that a ‘body of accepted theory’ has been developed through the publication of four collections of papers: *Overcoming Barriers to Student Understanding* (Land and Meyer 2006), *Threshold Concepts Within the Disciplines* (Land *et al.* 2008), *Threshold Concepts and Transformational Learning* (Meyer *et al.* 2010), and *Threshold Concepts in Practice* (Land *et al.* 2016). Since both Meyer and Land were part of the editorial team for each of these collections they can be regarded as offering an orthodox perspective; these therefore comprise a core of canonical texts. Hence, this formed the foundation of the literature review. Furthermore, the online Flanagan bibliography was used to identify other papers by either Meyer or Land. Liminality was provisionally defined as a time of transformative learning associated with stuckness, mimicry and oscillation and these terms were used as key words to select relevant further reading both from within the Flanagan bibliography and as ongoing search terms in Google Scholar and Scopus. Other literature, especially on constructivist learning theories such as concept change learning, was also perused.

The purpose of a literature review is to provide a thorough theoretical grounding for the subsequent research. This then shapes the research questions. However, classic Glaserian grounded theory method advocates a ‘blank slate’ approach so that the investigator can approach the data without theoretical preconceptions; this requires that the literature review be halted at an early stage (and may be restarted subsequently). On the other hand, Charmazian constructivist grounded theory recognises that theory is built between the investigator and the respondents; bias is minimised by making the investigator’s theoretical presuppositions explicit. This study hybridised Glaserian and Charmazian grounded theory; the literature was used to inform the study but there was a return to the literature following the results stage to help inform the analysis, especially for constructs such as ‘pausing’, ‘explanations’, ‘‘possible breakthrough ideas’’, ‘reflective self-dialogue’, and ‘promisingness’ that emerged during the empirical study.

The research questions were formulated as a result of the literature research.

In the literature review the concept of threshold concepts is critiqued. It is argued that the philosophical position of threshold concept theory is a matching of the ontological realism of threshold concepts with the epistemological constructivism of a transformation within liminality. It is argued that this pairing is not inconsistent and that another example is the philosophical position of science. However, in the case of threshold concepts this philosophical perspective has never been made explicit. As a result some of the key constructs such as liminality, stuckness and transformation have been insufficiently theorised. This allows for a delineation of the

problem space for this thesis: an attempt to develop signposts towards a retheorisation of the notion of liminality. Part of this programme is to develop a foundation on which to build. Some fundamental assumptions that underpin this study are therefore explored. Finally, the literature regarding liminality is intensively scrutinised in order to formulate the questions that will guide the research.

1.3.2: Chapter 3 Methodology and Method

The first part of this chapter uses an approach adapted from Crotty (1998, 3) to identify the most appropriate methodology for the empirical stage of this study. First the study was located within an appropriate epistemological background. Second, a set of questions (including whether the research was idiographic or nomothetic; etic or emic; descriptive, exploratory or interpretive; and quantitative or qualitative) was used to identify the theoretical perspective. Finally an array of available methodologies was evaluated against a set of theoretical and practical considerations before deciding upon a grounded theory approach. The particular version of grounded theory methodology adopted was hybridised from classic Glaserian grounded theory and Charmazian constructivist grounded theory so that it reflected the ontological realism and epistemological constructivism that the literature review had argued was the stance of threshold concepts scholarship.

A variety of possible methods were then considered. The method chosen, the ‘think aloud’ method, was adapted from that outlined by Van Someren *et al.* 1994.

1.3.3: Chapter 4 Results 1: Indicators of Liminality

The purpose of the first results chapter was to build a description of the liminal experience. After the first few interviews were transcribed it was realised that there was important data to be found not only in what participants said but also in how they said it. Extracts from the transcripts where the respondent seemed to be experiencing liminality, for example when they stated 'I don’t know' were analysed in depth. Common characteristics were sought; these provided indicators of liminality. These included pauses and hesitations, laughing, whispering and muttering, repetitions, and key lexical fillers such as ‘yeah’ and ‘so’. The evidence linking these characteristics to aspects of the liminal experience was considered.

Each of these indicators was then scrutinised to understand what feature of liminality they represented. For example, pauses seemed to indicate stuckness but repetitions and laughing seemed to occur when respondents seemed to be escaping stuckness.

1.3.4: Chapter 5 Results 2: Coding

Once the robustness of the indicators of liminality had been established, aspects of the liminal experience were elicited from the protocols. In grounded theory terms, these were the substantive codes. The constant comparison method was used to refine, merge and differentiate these categories. For example, early in the process there had been a single category for stuckness but the evidence suggested that this should be split into two. Some of the codes developed represented characteristics of liminality that had not been anticipated from the literature review.

Also in this chapter the various explanations offered are categorised and a hierarchy is suggested. Similarly, the various problem-solving strategies adopted by the respondents are described.

1.3.5: Chapter 6 Discussion and Second Literature Review

In this chapter the results gathered in the last two chapters are considered against the findings from other studies; a second literature review was undertaken in order to consider the findings that had been unexpected. For example, the types of explanation generated by the respondents in this study were compared with explanatory schemes from other writers. This enabled the development of an empirically based hierarchy of explanation.

Some of the researchers into liminality have suggested that some learners avoid the threshold and the results from this study were analysed to see whether there was evidence for this.

A number of the characteristics of liminality that had emerged during the empirical stage of this study were analysed in greater detail. These were also considered against the literature. For examples, examples of breakthrough thinking in the transcripts were compared with the literature of ‘eureka’ events to determine to what extent learning as transformation as envisaged by threshold concept scholars was supported by the empirical evidence and resonated with the ‘eureka’ literature.

Two aspects of the results called for directed searching of the literature because they had not been expected from the earlier literature review. These were the extent to which respondents appeared to talk to themselves while solving problems and the question of how participants assessed the potential of their ideas.

Finally, a new interpretation of the liminal experience was developed. By using this interpretation to develop a new perspective all of the characteristics of liminality observed within this study were able to be integrated in a coherent account.

1.3.6: Chapter 7: Conclusions and Recommendations

The first part of this chapter responds to the research questions posed at the end of chapter 2. Because of the reinterpretation of liminality, some of the research questions are no longer appropriate in their original form; this is explored.

The second part of this chapter explores the implications for pedagogical practice of the findings of this research.

The final part of this chapter develops the implications of this study for threshold concept scholarship. The aim of this study had been to develop the theorisation of threshold concept scholarship, paying particular attention to the fundamental concept of learning as transformation within liminality. The analysis of the empirical data suggested an alternative interpretation of liminality as a period of active exploratory learning. It is proposed that such a reinterpretation is not only able to provide a coherent map of the liminal experience but it can also position threshold concept

scholarship as a developing theory of learning. Potentially fruitful lines of further research are suggested.

Chapter 2: Literature Review

The case was made in the Introduction that threshold concept scholarship lacked a hard core of explicit theorisation and that to infer the meaning of some of the fundamental ideas it was necessary to consider what was implicit and unarticulated by examining not only the texts within the threshold concepts scholarship canon but also the context of these texts. This is the purpose of this literature review.

To do this I shall first use the literature to position threshold concept scholarship within the western educational cultural context. I shall argue that the philosophical foundations of threshold concepts match an ontological realism with an epistemological constructivism. I shall propose that the concept of liminality marks an important advance and that the understanding of learning as transformation within liminality which is implicit within much of the literature forms a key idea at the heart of threshold concept scholarship. However, I shall suggest that the necessary concepts of transformation and of liminality are at present poorly defined within the threshold concepts literature; to improve their definition I shall therefore review literature from outside this corpus. I conclude that transformation and liminality are still ideas about which there is insufficient clarity and that, therefore, it is necessary to collect empirical evidence.

2.1 Theories of learning and threshold concepts

As stated above, the immediate context that triggered the idea of threshold concepts was an enquiry into ways of improving the teaching and learning environment for

undergraduates at a time of rapid university expansion in the UK. Beyond that, the idea of threshold concepts has been developed within the cultural context of the western educational tradition.

There are a number of perspectives on learning in this context and they can be categorized in different ways. For example, Perkins (2008, 11) has a trinitarian view of knowledge as ‘possessive’, ‘performative’ and ‘proactive’. These might correspond to the stages of learning seen by Entwistle (2008, 27) in which learners start by ‘remembering facts’; move on to ‘being able to apply and use such knowledge’ and finally progress to trying to ‘make sense of ideas for themselves’.

Classification systems depend upon their underlying perspectives on knowledge and learning. The influential dualist system of Sfard (1998) which divides learning into learning as ‘acquisition’ versus learning as ‘participation’ is based on considering knowledge either as something you accumulate or as something you do. She therefore categorises constructivist views of learning together with transmissive views because they both involve ‘learning as gaining possession over some commodity’ (Sfard 1998, 6). An alternative categorisation, splitting constructivism from transmission, arises when the learner is regarded as either an active participant or a passive recipient in learning. The present study follows the tripartite classification of Watkins (2011, 7 - 11): learning as ‘being taught ... individual sense-making ... building knowledge as part of doing things with others’. It is argued below that threshold concepts contain aspects of all of these perspectives which simultaneously widens their appeal and makes them less easy to critique.

2.1.1: Learning as being taught; transmissive pedagogy

The first type of learning, often known as transmissive learning, assumes that 'knowledge is somewhere "out there", floating around in books or brains, and learning is about getting it into heads' Watkins (2011, 7). This 'fill-'em-up' metaphor for learning is consistent with an objectivist view of knowledge, knowledge as possession; what Perkins (2008, 4) characterises as 'money in the cognitive bank'. It justifies a transmissive pedagogy in which the essentially passive pupils have to pay attention to the utterances of an authoritative teacher in order to absorb facts. Failure to learn frequently implies 'some sort of a deficit in the learner – either in mental functioning or mental attitude (or having some barrier in your social background)' (Watkins 2011, 8).

Transmissive learning has long been the principal view of learning in western European culture, as evidenced in the long history of opposition to it. For example, Comenius (1907, 136), writing in the mid-seventeenth century CE but using a similar metaphor to Quintilian (2005) who was writing in the first century CE, warned that it is better to pour water gently into a jar with a narrow neck so as not to risk the liquid overflowing. It is still common today and deep-rooted; for example in the USA teaching is called 'instruction'. Newton *et al.* (2004, 104 - 105) maintain that the transmission model dominated classroom practice because 'pedagogy is essentially a conservative activity' (teachers tend to teach in the way they were taught) and because the external 'pressures ... of accountability and the marketization of education' has led teachers to focus on time-efficient activities that maximise assessment scores. It also enables a cost-effective one-to-many model. Gardner (2005, 214 - 217) suggests that a legacy of 'overcrowded classes, fixed classroom

furniture and limitations in books and equipment' has led to a pedagogy based on 'just talking at them'. Garbett (2011, 38 - 39), trying to explain why opposition was encountered when a new science curriculum based on constructivist principles was introduced in New Zealand, reports that teachers 'who are insecure in their knowledge of science' tended to adopt transmissive pedagogies because they found teaching for constructivist learning challenging.

There are aspects of the threshold concept idea that fit the transmissive metaphor. McCormick (2008, 53) asserts that the ideas of ‘an independent “conceptual space’’ and a ‘‘body of knowledge”’ that he finds in Meyer and Land (2003) characterise ‘knowledge as an object, independent of knowers’. Furthermore, the learner tends to be regarded as passive. Felten (2016, 3) notes that ‘undergraduate student voices have largely been absent’ from the work on threshold concepts. Agency belongs to the teacher who should ’carefully analyze what is needed to, metaphorically speaking, help students cross a conceptual threshold.’ (Talanquer 2014, 4). Failure to pass through the threshold is seen as threshold avoidance by Savin-Baden (2006, 164) or engagement in ‘mimicry or lack of authenticity’ (Meyer and Land 2003, 10) which matches the ‘learner deficit’ perspective that characterises transmissive pedagogies; Quinnell and Thompson (2010, 149) list no fewer than five ‘points ... where we observe student engagement wane’ each of which describes a failing in the learner. Even the transformation aspect of threshold concepts is often viewed as something which is done to the learner; learners sometimes appear to be largely passive as they undergo liminality.

2.1.2: Learning as individual sense-making; constructivist pedagogy

In the early seventeenth century CE, Francis Bacon and John Locke developed an inductivist model of learning in which ‘the student is confronted with the material and ... observes and then constructs, tentatively, general rules’ (McLean 1995, 28 - 34). Again the pupil was essentially passive: John Locke proposed that the mind of newborn was a ‘blank slate’ on which parents and teachers could inscribe knowledge (Lawton and Gordon 2002, 83). However this has been critiqued since Emerson (1893, 80) who gave lectures which developed a digestive metaphor for learning: ‘A mind does not receive truth as a chest receives jewels that are put into it, but as the stomach takes up food into the system. It is no longer food, but flesh, and is assimilated’. This implies that the learner makes changes to what is being learnt before the knowledge becomes part of the learner. Emerson (1893, 16) also taught that ‘every river makes its own valley’; the learner actively changes the world. Dewey built on Emerson’s ideas, claiming that ‘Education is not an affair of 'telling' and being told, but an active and constructive process.’ (Dewey 1916, 46). This has then developed into the constructivist position.

‘The core commitment of a constructivist position’ according to Driver, Asoko *et al.* (1994, 5) is that ‘knowledge is not transmitted directly from one knower to another but is actively built up by the learner.’ For Watkins (2011, 9) the learner is ‘active in constructing sense from the environment’ and ‘is not seen to discover an independent, pre-existing world outside the mind of the “knower”’. Nevertheless, what the learner acquires is often described as a ‘conception, a schema, or a mental representation’ and as such ‘learning as gaining possession over some commodity’ (Sfard 1998, 6). This is the reason that Sfard classifies constructivist perspectives on

learning in the same category as transmissive pedagogies; both being part of an ‘acquisition metaphor’ for learning. On the other hand Lakatos (1970, 104) makes a fundamental distinction between ‘passivist’ theories of knowledge such as empiricism and ‘activist’ theories of knowledge. The separation of constructivist and transmissive perspectives in the tripartite classification system of Watkins (2011) can therefore be justified.

Taylor (2006, 98) links the construction of understanding by students with the transformational aspect of threshold concepts. This perspective on learning foregrounds the journey of the learner through liminality, which is ‘simultaneously transforming and being transformed by the learner as he or she moves through it’ (Meyer and Land 2005, 380). The problems learners experience, such as stuckness, oscillation, and mimicry, are explored; a pedagogy of uncertainty is suggested. The focus is still on the individual learner; Land *et al.* (2014b, 6) talk of the ‘individual learner’s liminal state.’ These aspects of threshold concept scholarship seem to imply a constructivist model of learning.

2.1.3: Learning as building knowledge as part of doing things with others; social constructionism

For Sfard (1998, 5 - 6) the alternative to the ‘acquisition metaphor’ is the ‘participation metaphor’. This has been popularised by Lave and Wenger (1991, 29) as the notion of ‘legitimate peripheral participation’ which is how learners ‘participate in communities of practitioners and ... move forward toward full participation in the sociocultural practices of a community.’ Watkins (2011, 11) points out that ‘meaning

is constructed together in social activity, not individually in people's heads. Human learning is necessarily and fundamentally social.'

This aspect has been endorsed by some threshold concept scholars. For example, Kabo and Baillie (2010, 306) propose that 'part of grasping a threshold concept seems to involve the learner moving ... from a novice mindset to an expert mindset', Cousin (2014, 25) states that 'alongside conceptual mastery, students have to master the business of entering studenthood', and Hokstad *et al.* (2016, 326) describe liminality as 'an initiation process, where the learner is passing from a stage of innocence to a stage of insight and belonging in a group sharing the same kind of insight'.

2.1.4: Threshold concepts draws on each of these traditions

The roots of threshold concept scholarship can thus be found in all three perspectives of learning. As Kutsar and Karner (2010, 383) state, the 'Threshold concepts perspective ... integrates several theoretical perspectives combining learning theories with social constructivism'. This suggests a reason why Irvine and Carmichael (2009, 106) found that threshold concepts were interpreted differently by people from different disciplines which in turn might explain the broad appeal of threshold concepts across an array of disciplines ranging from engineering to anthropology. Furthermore, Sfard (1998, 10 - 11) suggests that having a plurality of metaphors is a strength. The reasons she gives are pragmatic ones: for example it is a 'protection against theoretical excesses' and 'no two students have the same needs'.

Sfard's position can be justified by interpreting the theoretical perspectives as nothing more than metaphors. However, Schwartzman (2010, 22) criticises the overdependence on 'description, metaphor and analogy' of current threshold concept scholarship. Webb (2016, 301) asserts, 'threshold concepts provide an emergent theoretical framework to reconsider research and practice in higher education'. But before this 'theoretical framework' can fully emerge it is necessary to move from metaphor to theory. For this to happen the philosophical foundations of threshold concept scholarship must be established and internal contradictions resolved.

2.2: The key characteristics of threshold concepts

2.2.1 The properties associated with threshold concepts

The most influential part of Meyer and Land (2003) was the list of properties which were associated with threshold concepts: transformativity, irreversibility, integrativity, boundedness and the association with troublesome knowledge. Over the years this list of properties has generated some controversy. For example, Barradell (2013) asks 'how many of the five characteristics should a concept possess to be regarded as a threshold concept? Are some characteristics more important than others? If a concept is troublesome and integrative but not transformative, is it still a threshold concept?' Indeed, the initial list suggested that the first three properties were more or less essential and the last two optional.

Sibbett and Thompson (2008, 229) have extended the types of troublesome knowledge with what they call 'Nettlesome knowledge ... elements of knowledge that

are deemed taboo in that they are defended against, repressed or ignored because if they were grasped they might “sting”’. And Davies and Mangan (2005) have suggested that troublesomeness is inherent in transformation because a threshold concept ‘requires reconfiguration of previously acquired knowledge’.

Links have been seen between the characteristics of ‘bounded’ and ‘integrative’. Davies and Mangan (2005) suggest that the threshold characteristic of bounded is linked to the threshold characteristic of integrative because ‘the looser the integration, the more the boundaries of a subject become open to debate’. Integrativity and boundedness thus become connected in a mutually reciprocal relationship. In a concept network a concept that is more connected than other concepts (as Scott and Harlow 2012 suggest a threshold concept might be) will tend to form a cluster; the outer concepts will be relatively less connected and therefore the cluster will appear relatively isolated and so ‘bounded’. Wimshurst (2011, 303) suggests ‘powerful or keystone concepts may offer coherence in understanding’; which links integrativity to the coherence; nevertheless he suggests that emerging cross-disciplinary studies may also have ‘generic’ threshold concepts.

Irreversibility has also been much debated. Some theorists (for example, Booth 2006, 175) suggest that irreversibility is a necessary corollary of transformativity but not everyone agrees that threshold concepts are irreversible. Scott and Harlow (2012) interviewed an admittedly small sample of engineers who had used identified threshold concepts more than five years ago. They found their participants ‘often claimed to fully understand a concept, but then surprised us and themselves by not being able to describe it to us’ and concluded ‘we have seen no evidence that our

TCs are any more irreversible than other concepts.' There seem to be three possibilities: firstly, not all threshold concepts are irreversible; secondly, the concepts Scott and Harlow tested were not threshold concepts; and thirdly, the engineers had never passed through the thresholds. However, the concept of irreversibility does not necessarily mean that passing through the threshold eliminates prior learning nor does it 'exclude subsequent modification or rejection of the concept for a more refined or rival understanding' according to Cousin (2006a).

The most important feature of a threshold concept is that it is transformative. Although Rowbottom (2007, 266) asks 'what concept is not [potentially] transformative?' and Land *et al.* (2014b, 3) seem to concur when they state that 'all learning to whatever degree involves both a conceptual shift and also an ontological shift from an earlier version of yourself', threshold concepts are distinctive in the extent of the transformation they achieve. Perkins (2006, 44) elevates transformativity from a non-negotiable property into an inherent part of the identity of a threshold concept: threshold concepts are 'by definition transformative.' For Quinlan *et al.* (2013) the 'non-negotiable features of threshold concepts' are both transformation: epistemological and ontological transformation. And Walker (2013) suggests that the idea of transformation is so powerful 'that it can be seen as the super-ordinate category under which the remaining characteristics of TCs tend to be grouped.'

The early focus on properties has led to a substantial proportion of threshold concept scholarship becoming devoted to the identification of threshold concepts in a variety of disciplines. For example, in *Threshold concepts and Transformational Learning*

(Meyer *et al.* 2010), the key text in 2010, over half the papers explore threshold concepts in clinical education, geology, philosophy, biology (twice), economics (thrice), electrical engineering, computer science, nanoscience, accounting, and design. This has led to calls for threshold concepts scholarship to go 'beyond identification' (Irvine and Carmichael 2009, 116).

2.2.2: Transformation and liminality; two interpretations of transformation

If transformation is the supreme characteristic of threshold concepts, then it is matched in importance by the notion of liminality. Although in Meyer and Land (2003, 10) liminality was regarded as a consequence of failure to pass through the threshold, by Meyer and Land (2005, 376) it was compared to a rite of passage: 'liminality itself is then the process of transformation at work'.

This marks a key advance. Previously most of the studies had noted the situation before learning and that after learning. As Schwartzman (2010, 27) points out, most of the characteristics of threshold concepts focus on the problems before learning (troublesome knowledge) or the (hoped for) outcomes of learning (an irreversible transformation leading to bounded, integrative understanding); the concept of liminality offers an opportunity to focus on 'how learning happens'.

In fact, the 'before and after' approach has characterised many other theories of learning. For example, Vygotsky wrote in the 1930s that 'until recently the student of concept formation was handicapped by the lack of an experimental method that would allow him to observe the inner dynamics of the process' (Vygotsky and Kozulin 1986, 105); liminality is the frame within which the 'inner dynamics' take

place. Posner *et al.* (1982, 211) stated that 'there has been no well-articulated theory explaining or describing the substantive dimensions of the process by which people's central organizing concepts change from one set of concepts to another set, incompatible with the first'; liminality is the period during which the change happens. Bruner (1997) pointed out that although Piaget had talked about 'disequilibration' causing learning, 'the dynamics of disequilibration have never been clear'; by studying liminality these dynamics may be clarified. Constructivists Fosnot and Perry (2015, 20) use terms borrowed from complexity theory to describe Piaget's equilibration being accomplished in a 'transition zone'.

The fundamental advance made by threshold concept scholarship is therefore the characterisation of learning as 'transformation during liminality'. Rather than becoming a property of something to be taught, transformation becomes a process. This is problematic because on the face of it these two versions of transformation are inconsistent. As Meyer and Land (2005, 379) state they appear to 'entail different spatial characteristics'.

The first version of transformation ties it to the threshold concept which O'Brien (2008, 293) suggests is seen as an 'object of knowledge.' Furthermore, although Cousin (2006a, 4) cautions against 'an inherent tendency to invite congealed understandings' and Meyer and Land (2005) reject objectivism and state that threshold concepts are 'discursive in nature', Land and Meyer (2010, 75) say that 'in terms of charting students' learning journeys threshold concepts literally are the waypoints to be navigated.' Schwartzman (2010, 26) believes that the threshold concept view of learning is to hoist the learner 'over an existing (provisionally) stable

threshold in a fixed world'. These are ontologically objectivist understandings of the reality of threshold concepts in what Ricketts (2010, 45) calls the 'disciplinary world'.

On the other hand, Cousin (2006a, 4) asserts that 'grasping a threshold concept is transformative because it involves an ontological as well as a conceptual shift'. This could be taken to mean that the learner's understanding of reality changes but, although this is nowhere explicitly stated, other threshold concept scholars appear to hold a more subjectivist view of ontology. For them ontology means not just the individual's understanding of the world but also their understanding of their place within the world; it is overlain with notions of self-hood and identity. Thus Wearn *et al.* (2016, 223) suggest that 'learning in health professions is profoundly ontological - it is about "becoming" a practitioner.' Kiley and Wisker (2010, 412) describe ontology as 'the ways in which they [the student experiencing liminality] see themselves … and the world'. And Land *et al.* (2014a, 201) propose that there is in liminality 'a reformulation of the learner's meaning frame ... and an accompanying shift in the learner's subjectivity. Hence it entails both a conceptual and an ontological shift'.

This second version of transformation is fundamentally constructivist, as Irvine and Carmichael (2009, 104) point out. However, the connection between threshold concepts and constructivism is largely unacknowledged. Out of more than 13,000 entries on the key words index of the Threshold Concepts bibliography maintained by Flanagan (2017), representing more than 1600 papers, there are only seven mentions of construct, constructive, constructivism or constructivist, and two of

constructionist. In order to maintain Irvine and Carmichael's identification it is necessary to seek unarticulated evidence.

In 2006 the first key text of threshold concepts was produced entitled *Overcoming Barriers to Student Understanding: threshold concepts and troublesome knowledg*e. Its third chapter (and the first not written by Meyer and Land, which assigns it a prominent place within this text) was entitled 'Constructivism and troublesome knowledge' (Perkins 2006). In their original paper Meyer and Land (2003) had acknowledged Perkins as the inspiration behind their ideas about troublesome knowledge; the positioning of this paper and the subtitle of the book gave his idea prominence. In it he rejects 'ideological constructivism' in favour of a 'pragmatic constructivism ... like a Swiss army knife with various blades for various needs' (Perkins 2006, 45) which is more than just an endorsement of the miscellany of sources referenced by the original papers of threshold concepts. He also states that 'troublesome knowledge of various kinds invites constructivist responses' (Perkins 2006, 45). It is thus possible to trace a connection. Meyer and Land (2003) link threshold concepts with troublesome knowledge; Perkins (2006) links troublesome knowledge with constructivism.

Constructivist links reappear in the canonical text of 2010 *Threshold Concepts and Transformative Learning* (Meyer *et al.* 2010). In one chapter Timmermans (2010, 3) declares that 'learning is an active process of meaning-making', which is very much a constructivist perspective. In another chapter, Mead and Gray (2010, 100) assert that the characterizations of the transformative, irreversible, and troublesome characteristics of threshold concepts 'clearly make reference to the way learners

structure their understanding' and therefore 'reflect the constructivist flavour surrounding the threshold concept idea'.

Finally Meyer and Timmermans (2016, 32) imply that knowledge about threshold concepts may be constructed at least by teachers in higher education.

2.3 The ontology and epistemology of threshold concepts

It is therefore proposed that threshold concept scholarship is underpinned by a ontologically realist view of knowledge but a constructivist view of learning. At first sight this appears incoherent. Is it possible to develop a theory that is ontologically realist but epistemologically constructivist? Not according to Guba and Lincoln (1989, 43 - 44) who believe that 'the constructivist paradigm .... denies the existence of an objective reality'. However it is argued below that such a combination is possible. The examples given are physics and education which are the contexts of this study. It may be that the pairing of ontological realism and epistemological constructivism is more widespread but even a single example is enough to demonstrate that a body of scholarship with such a philosophical foundation can be coherent.

2.3.1: Physics as ontologically realist and epistemologically constructivist

Physics is an example of a realist ontology matched with an epistemological constructivism. It seems common among non-scientists to make the assumption that science, especially physics, is positivist. However, the research enterprise of science is to question what we think we know and to build continually refined models of

reality. As Solomon (1993, 12) points out, the scientist who ‘seeks quietly for eternal truths and Nature, using ... disinterested experiment and incontrovertible mathematics’ is a caricature. Quantum physicist Bohm (1996, 57) makes the point that ‘if we supposed that theories gave true knowledge, corresponding to “reality as it is”, then we would have to conclude that Newtonian theory was true until around 1900, after which it suddenly became false’ which he describes as an ‘absurd conclusion’.

This is not just a modern position. In book 3 of *Principia*, first published in 1687, Newton (1850, 385) advised that ‘we are to look upon propositions collected by general induction from phenomena as accurately or very nearly true ... till some time as other phenomena occur, by which they [the propositions] may either be made more accurate, or liable to exceptions’ but modern science is so technologically mediated that interpretivist views are mainstream. ‘Bare facts are never self-explanatory: they require interpreting’ conclude Toulmin and Goodfield (1967, 95). Thus Hanson (1965, 4) shows how while one biologist may see an amoeba as a cell on a par with other tissue cells, another may see it as an animal with a single cell. And most observations are made using a plethora of measuring instruments. These are known to distort observations (for example, when you insert an ammeter into an electrical circuit to measure the electric current you reduce the current because a very small amount is used to operate the ammeter) and impose a potential distortion of reality; the first reaction of most researcher scientists to an unexpected result is to check whether the measuring instruments are operating properly, perhaps by repeating the experiment (Lakatos 1970, 107). ‘Direct’ observation is also often not satisfied in modern physics because many discoveries involve chains of inference,

often technologically mediated. For example, the ‘observation’ of a planet that has been discovered orbiting a star outside our solar system depends on a pattern of tiny changes in the frequency of one of the spectral lines of light coming from the parent star of the planet. This allows one to infer how the star is ‘wobbling’ which in turn allows one to infer the position and mass of the planet by assuming that the wobble is caused by the gravitational pull of the orbiting planet. Nevertheless, scientists do not reject the notion of a fundamental, if perhaps unknowable, reality. Heisenberg's Uncertainty Principle does not deny reality as Guba and Lincoln (1989, 92) appear to believe; Heisenberg (1990, 42 - 43) stated that ‘London exists whether we see it or not’ but there is a ‘subjective element of incomplete knowledge’. This interpretation therefore suggests that there is a reality but that our knowledge of it can never be complete: it accepts ontological realism while denying epistemological positivism.

Scientists are sometimes criticised for believing that their discipline can be value-free. Crotty (1998, 39) suggests that the historical and cultural backgrounds of academics influences their thinking and Latour and Woolgar (1979) suggest that scientific facts are socially constructed. For example, Maxwell, surrounded by mechanical engineering in Victorian Britain, imagined space being filled with tiny spinning wheels that transmitted electromagnetic waves like a set of cogs (Mahon, 2004, 90 - 110). Solomon (1993, 15) states that ‘the design of experiments, as well as the results from them, could now be viewed through culturally tinted spectacles.’ The neutral and unbiased seeker after truth described by Newby (2014, 37) is an ideal that is ‘ideologically attractive but almost impossible to implement’ (Eraut 2012). Nevertheless it is probably worthwhile to try to be less biased and more accurate and if one cannot shed one’s presumptions at least to admit them. Sokal and Bricmont

(1998, 80) compare scientific research to criminal investigation: there may be no perfect way to go about it, although some ways are worse than others; one may never solve the crime but this does not deny the reality that there is something to be solved. Again, the presumption is that there is a truth but our understanding of it that we build will always reflect our presuppositions. This is a position of ontological realism and epistemological constructivism.

2.3.2: Ontological realism and epistemological constructivism in education

Educators might recognise the same ontologically realist but epistemologically constructivist pairing in the match between the curriculum and how it is taught. In general that which is taught is treated as if it were true (for example when assessing how well a learner has learnt) even though the concepts in the curriculum are at one remove from the concepts of the original discipline. The pairing of ontological realism with epistemological constructivism is highlighted by the dilemma faced by teachers operating a broadly constructivist pedagogy such as ‘discovery’ teaching when they seek to create situations in which a learner will be able to construct their own understanding of the world but at the same time seek to ensure that the learners learn the orthodoxy that the teacher intends to transmit as Driver (1983, 3) points out. In the case of school science teaching (and to some extent in other subjects too) this issue is given a further dimension because some of the learners may progress to become researchers in science. To be allowed access to higher education they must learn the orthodox fact-based knowledge well enough to pass gateway assessments. Thus the current orthodoxy must be treated as if it represents reality but at the same time learners need to retain an attitude of scepticism and the skills of independent

thought and enquiry which will enable them eventually to engage in research and, where necessary, undermine the current orthodoxy and develop a new one.

2.4 Understanding what is meant by 'transformation'

It has been established that an interpretation of learning as a fundamentally constructivist 'transformation within liminality' is compatible with an ontologically realist understanding of a threshold concept universe. In order to further develop threshold concept scholarship as a theory of learning it is now necessary to understand better what is meant by the notions of 'transformation' and 'liminality'.

2.4.1: What is transformed during transformative learning?

'What "form" transforms?' asks Kegan (2009, 35). There are many different answers. For Mezirow (2000, 19) what is transformed are 'points of view, or ... habits of mind'. Land *et al.* (2010, xi) characterise transformative learning as a 'reconfiguring of the learner's prior conceptual schema'. For Davies and Mangan (2008, 39) there are three levels of transformative conceptual change: at the 'basic' level everyday experience is integrated with disciplinary ideas; at the 'discipline threshold concepts' level 'subject discipline ideas' are 'integrated and transformed through acquisition of theoretical perspective'; and at the 'procedural' level 'discipline specific narratives and arguments [are] transformed through acquisition of ways of practising.'

Meyer and Land (2003, 4) understood transformation as 'a significant shift in the perspective of a subject, or part thereof'. Schwartzman (2010, 40) suggests that the

transformation involves a rearrangement of ‘the contents of the field of consciousness’; some elements move to the centre, perhaps from outside, and others move to the edges. Walker (2013) asserts that schema ‘are reorganized when incoming data reveal a need to restructure the concept ... they are organized in a way that is meaningful to the individual.’

Some threshold concept scholars (for example, Meyer and Land 2003, 4; Meyer and Land 2006b, 21; Allen 2014, 34; Land *et al.* 2014b, 3) suggest that what is transformed is the learner’s identity. This is sometimes seen as an ontological shift (for example, Shanahan *et al.* 2010, 207) as explained above in section 2.2.2. Learning as identity transformation seems to be reinforced when liminality is compared to a rite of passage, for example in Meyer and Land (2005, 376) who use the example of adolescence in western culture. This is more than a simple ritual such as a degree ceremony because ‘as a result of the ritual the participating individual acquires new knowledge and subsequently a new status and identity within the community’ (Meyer and Land 2005, 376). But the statement ‘acquires new knowledge’ suggests that in threshold concepts the participative aspect of identity transformation is hybridised with the acquisitive concept of knowledge.

Inevitably, the transformation has an affective dimension, causing ‘a shift in values, feeling or attitude’ (Meyer and Land 2003, 4).

As a result of the transformation ideas are integrated (Taylor and Meyer 2010, 189), and there may be the ‘adoption of an extended discourse’ (Meyer and Land 2005, 375).

2.4.2: What are the characteristics of transformative learning?

Transformation involves loss. Meyer and Land (2005, 376) talk of the need for the participant to 'strip away, or have stripped from them, the old identity'. The process of transformation 'may be sudden or it may be protracted over a considerable period of time' (Meyer and Land 2003, 1). Land *et al.* (2010, xi) concur; transformation requires 'a letting go or discarding of any earlier conceptual stance'. Perhaps because of this, transformation is irreversible: 'There would seem to be no re-winding of the transformative process.' (Meyer and Land 2005, 377).

Savin-Baden (2008, 80 - 81) suggests that transformation is instigated when the learner perceives 'a catalyst to change which results in disjunction'; disjunction is described as sometimes being 'a little bit like hitting a brick wall in learning' and at other times 'a sense of vague stuckness, a feeling of confusion or an idea that one has come across some difficulty or troublesomeness but what that is, is not entirely clear'. In other words, something happens which results in the learner becoming stuck. Transformation is necessary to unstick stuckness.

Descriptions of how transformation happens are more difficult to locate. Land *et al.* (2010, xi) state that 'within the liminal state an integration of new knowledge occurs which requires a reconfiguring of the learner's prior conceptual schema' and Schwartzman (2010, 34) suggests that it happens through 'reflectiveness (taking on

the challenge of uncertainty and its effective components by engaging with the unknown as unknown) [*sic*]'.

Thus the threshold concept literature provides an outline description of transformation but the details are vague and ambiguous. This is acknowledged: Timmermans (2010, 3) describes the 'transitions that characterise the learning process' as 'nebulous'. Some descriptions, such as schema reconfiguration, favour a cognitivist perspective; whereas identity reconstruction offers a more social constructionist point of view. Schwartzman (2010, 40) suggests that 'the mechanism remains mysterious.' If it is important to understand transformative learning it may be necessary to consider literature from outside the threshold concept corpus. This is to follow the lead of Meyer and Land (2003, 4), who cite the work on transformative learning by Mezirow (1978), and Land *et al.* (2010, xiii) who find in fiction images of transformation as decay.

2.4.3: Notions of transformative learning from outside the TC tradition (i): concept change learning

Mezirow (1990, 13) proposes that perspective transformation is caused by either 'reflection upon anomalies' or 'an externally imposed disorienting dilemma'. He describes three stages which are echoed by Land *et al.* (2010, xi): 'alienation' which provokes the liminal state; 'reframing, restructuring one's conception of reality and one's place in it' which prefigures Land *et al.*'s reconstitution phase; and the postliminal 'contractual solidarity' (Mezirow 1977, 158). By 2000 he proposes that

transformation is achieved by a learner ‘becoming critically reflective of their assumptions and aware of their context’ and ‘reformulating reified structures of meaning by reconstructing dominant narratives’ (Mezirow 2000, 19).

It has been argued above that threshold concepts scholarship aligns with a fundamentally constructivist perspective. Taylor (2006, 98), an early contributor to the threshold concepts literature, links constructivism with transformative learning: ‘students will construct their own understanding as they transform their knowledge’. Hence there is a case to be made for seeking the parallels with other constructivist learning theories such as the work of the concept change learning theorists. There have been calls for this from threshold concepts scholars: Bhola and Parchoma (2016, 37) have noted that ‘understanding of threshold concepts involves the mechanism of conceptual change’. Entwistle (2008, 23) points out the availability of ‘a vast literature on conceptual change’. Reimann and Jackson (2006, 117) point out that ‘research about conceptual change has highlighted that everyday, commonsense conceptions often override scientific ones.’

Nevertheless my survey of 86 bibliographies in the four key threshold concept texts (Meyer and Land 2006, Land *et al.* 2008, Meyer *et al.* 2010, Land *et al.* 2016) found that constructivists Ausubel and Piaget were cited three times each, Dewey four times and Vygotsky eight times. Only one paper mentioned the work of Driver, a key concept change learning theorist, and there was no mention of the work of Carey. Threshold concept scholarship has distanced itself from the constructivist concept change learning.

It might be speculated that one of the reasons for the separation of the two models of learning is that threshold concepts were developed by discipline specialists in higher education to improve undergraduate teaching and have primarily stayed within this context (although there are studies of younger age groups, for example Ashwin 2008) while concept change learning has historically focused primarily on primary school children learning science (although Driver often worked with secondary school children). Context can affect process and maturational theories of learning such as Piagetian stage theory create expectations that young children will learn in in a different way from young adults. On the other hand Kegan (2009, 41) asserts that ‘transformational learning is not the province of adulthood or adult education alone’.

The threshold concept scholars themselves offer a rather more substantive justification for the divide. Entwistle (2008, 23 - 24) believes that ‘the research on conceptual change tends to focus on isolated concepts, but in higher education we are also concerned about how students bring together groups of concepts so as to understand topics or theories’. Meyer and Timmermans (2016, 35n) also suggest that concept change learning tends to focus on how a single concept changes whereas the integrative nature of threshold concepts requires transformation of multiple concepts. Illeris (2007, 27) suggests that so many ‘mental schemes’ are restructured during transformative learning that a ‘restructuring of the organisation of the self’ is caused. However, he points out elsewhere that no-one has so far laid down ‘clear criteria for where the borderline goes between this type of learning and other learning’ (Illeris 2007, 47).

Concept change theorists usually distinguish between ‘assimilation’ and ‘accommodation’; these ideas derive from the work of Piaget. He theorised that when an individual encountered new learning their mind already contained knowledge in the form of schemata; this knowledge was used to interpret the new information (Piaget 1977, 6 - 7). If the new information was broadly compatible with the old knowledge the new information might be modified and added to the schema leaving the schema largely unchanged in a process Piaget called 'assimilation' (there is perhaps an echo here of Emerson’s digestive metaphor) which he defined as the ‘incorporation of an outside element ... into the subject’s sensorimotor or conceptual scheme.’ If the new information was incompatible with the schema 'accommodation' took place: changes were made to the schema.

Ausubel and Robinson (1969, 50 -67) elaborated Piaget’s ideas. Instead of schemata they described the 'cognitive structure' which is 'the facts, concepts, propositions, theories, and raw perceptual data that the learner has available to him at any point in time' and they suggested that when the material to be learned is 'an extension, elaboration, modification, or qualification of previously learned properties' there is a minor rearrangement of the learner’s cognitive structure similar to Piaget’s assimilation but when the new material contains 'general and inclusive ideas ... under which several *established* ideas may be subsumed' there would be a more extensive rearrangement such as Piaget’s accommodation suggests. Ausubel *et al.* (1978, 87) called this latter process 'concept formation'. As well as the cognitive structure being rearranged, Ausubel pointed out that the concept being learned might also be modified, being 'perfected' or 'sharpened’ (Ausubel and Robinson

1969, 124 - 125) so that the new concept formed is not necessarily the same as the concept presented.

Driver popularised the idea of learning as 'a process of conceptual change' (Driver, Asoko *et al.* 1994, 6). She likened learning to the arrival of a new pupil in class. 'When he arrives, there are various possibilities for what might happen: he might not relate with the other students at all and remain isolated; he might join a group that already exists; or his presence might provoke a reorganization of friendship groups of the class as a whole' (Driver *et al.* 1985a, 5). This analogy recognised that assimilation and accommodation, however they were to be called, were extremes of the same phenomenon. In fact Treagust and Duit (2009, 91) refer to assimilation as 'weak' conceptual change and accommodation as 'strong' conceptual change, pointing out that assimilation and accommodation are not entirely separate categories but labels for overlapping domains and that the schema is always changed to some extent.

This suggests that the fundamental difference between concept change learning and threshold concept scholarship is a matter of degree. Accretionism, 'knowledge acquisition which includes enrichment of an existing conceptual base' (Carey and Spelke 1996, 523) and 'efforts to add compatible ideas to elaborate our fixed frames of reference' (Mezirow 2000, 18) are outside the focus of threshold concept scholarship. This positioning of transformative learning is reinforced by Illeris (2007, 39 - 47) who subdivides learning into four categories which he calls cumulative, assimilative, accommodative and transformative learning; he places transformative learning at the end of accommodative. The idea that transformation involves the

radical rearrangement of relationships between previously learned concepts, the changes perhaps cascading through the network, offers the potential for a deeper understanding of learning as transformation within liminality.

2.4.4: Notions of transformative learning from outside the TC tradition (ii): 'eureka' events

As some point during the liminal experience the understanding of the learner is transformed. Meyer and Land (2006a, 3) state that a 'transformation may be sudden or it may be protracted over a considerable time'. This echoes Mezirow (2000, 21) who describes transformations as either 'epochal, a sudden, dramatic, reorienting insight' or 'incremental'. Illeris (2007, 47) also recognises that transformative learning 'can take place as a sudden breakthrough' although he considers that a longer process is more common. But most threshold concept scholars focus on the rapid transformations. Entwistle (2008, 25) describes the moment of transformation thus: 'Different facets of a topic come together simultaneously – "click into place" - to create a satisfyingly complete picture, along with a feeling of confidence that the understanding can be used to provide adequate explanations that fulfil present requirements.' Sometimes this is linked to what is sometimes called the 'eureka' effect. Orsini-Jones (2010, 293) discusses 'the "eureka" moment of grasping the concept'. Easdown (2014, 44) links learning threshold concepts in maths with eureka moments. Shanley and Dalley-Hewer (2017, 16) link acquiring a threshold concept with 'the "light bulb moment" that our students described'. And Irvine and Carmichael (2009, 106) found seminar participants describing 'transformative "eureka" moments

involving radical transformation of conceptual frameworks'. Can the literature on the 'eureka' effect help us to understand the notion of transformation?

Eureka events are most commonly described using visual imagery such as a 'bolt from the blue' or 'sudden flashes of insight.' (Hofstadter 1980, 50). Metcalfe and Wiebe (1987, 238) report a 'sudden, unforeseen, flash of illumination'. For Bohm (1996, 54) 'a flash of understanding' produces a 'display' which 'is inseparable from the act of primary perception itself'. 'Eureka' events solve in*sight* problems. They are often considered to be solved using *imag*ination. A common cartoon meme is to show a character with an illuminated light-bulb over their head as they think of something. The sort of eureka events that religious mystics achieve is often described as en*light*enment. However, alternative sense modalities are also employed when describing eureka events. To call them 'aha' moments is to suggest an auditory mode. Or one can suddenly 'grasp' an idea.

Hofstadter (1980, 613), Kneller (1965, 53) and Metcalfe and Wiebe (1987, 238) also used the word 'sudden' to describe the eureka experience; Danek and Wiley (2017) prefer the phrase 'all at once'. A solution to an insight problem will 'emerge suddenly or discontinuously' (Ausubel and Robinson 1969, 509); it 'emerges into awareness suddenly' (Kounios and Beeman 2009, 210); in fact, Kounios and Beeman (2014, 74) see suddenness as a defining feature of an insight solution. Keefer (2015, 17) stated that many doctoral students 'described their breakthroughs coming through sudden experiences'. Perkins (2000, 34), Runco and Sakamotu (1999, 71) and Davidson (1996, 147) report an experiment in which subjects assessed how warm or cold they were at 15 second intervals during the puzzle solving process, insight

problems typically showed no change in warmth rating until a sudden jump near the end. Jausovec and Bakracevic (1995, 16 - 18) found a sudden ‘extreme increase’ in heart rate in the 15 seconds immediately prior to solving insight problems. Similarly Ball *et al.* (2015, 80) found that ‘a sudden burst of high-frequency (gamma band) neural activity in the right hemisphere’ often accompanied the solution of insight problems.

This suddenness is often linked with the lack of any clear provenance for the breakthrough thought. Laukkonen and Tangen (2017, 198) and Thomas *et al.* (2013) describe ‘eureka events’ as ‘unexpected’. Wegner (2002, 83) describes this as being without a preview in thought and Topolinski and Reber (2010, 402) state that the insight idea ‘pops into mind abruptly and surprisingly’.

Other researchers describe the affective components of discoveries. Danek and Wiley (2017) state that one of the ‘key components’ of ‘Aha! experiences’ is the ‘joy of discovery’. Finke *et al.* (1996, 36) suggest that ‘the most important motivator for creative thought is the joy of discovery.’ Bruner (1961, 21 - 32) suggests that discovery is autotelic, a reward in itself. Dewey (1926, 187) talks of children experiencing ‘the joy of intellectual constructiveness’. Topolinski and Reber (2010, 402) call it a ‘genuine positive affective experience’; Gopnik (2000, 312) as an ‘expression of joy’, akin to an orgasm.

The cause of this joy is the fact that at the moment that the breakthrough occurs the thinker has the feeling that the breakthrough idea is the solution for which they have been searching. The word ‘eureka’ is from the Greek meaning ‘I have found it’.

Gopnik (2000, 314) says ‘suddenly, it all becomes clear; all at once, everything makes sense‘. Bohm (1996, 54) describes that the aftermath of a ‘eureka’ event as ‘a new totality … contradiction and confusion has vanished’ although he is clear that the understanding gained may need further testing. Danek and Wiley (2017) state that one of the ‘key components’ of ‘Aha! experiences’ is the ‘confidence in being correct’.

There are thus a number of characteristics that are common to most, if not necessarily all, ‘eureka’ events. They are sudden. They are typically unbegotten, without any discernible provenance. They are often, but not always, described in terms of visual imagery. They are usually accompanied by feelings of pleasure and, in particular, feelings of certainty.

If resonances are found between transformative learning and the ‘eureka’ effect it would become necessary to consider a theoretical justification for them. The alternative perspectives of Mezirow, of the concept change learning theorists, and of the literature surrounding the ‘eureka’ effect offer a coherent albeit cognitivist interpretation of transformative learning which could form the foundation for a theory. Take the suggestion of Baillie *et al.* (2013, 235) that disciplines are ‘complex webs of concepts, some threshold’. Follow Talanquer (2014) in proposing that learning means that a learner ‘will likely have to dismantle, set aside, coalesce or separate existing assumptions, concepts and ideas while building new ones’. Assume that the concept networks surrounding threshold concepts are formed of highly integrated links. Then, as Donald (2002, 41) suggests, ‘the close interdependent relationships among the course concepts on the concept map would lead to an all-or-nothing

learning pattern'. If transformation in liminality is effected by the radical restructuring of prior knowledge the suddenness of the 'eureka' event would be explained. If the restructuring led to a new way of looking at the problem this would also resonate with the explanation of Laukkonen and Tangen (2017) that 'the solution may be immediately obvious' because it is found by re-interpreting the problem from a different perspective.

2.5: Theorising liminality

As with the attempts above to clarify the understanding of 'transformation', the threshold concepts literature will be used as the primary source of ideas about 'liminality' but literature outside the corpus will also be considered where it is thought necessary.

Cousin (2008, 265), has suggested an analogy between liminality and Vygotsky's Zone of Proximal Development (Vygotsky and Kozulin 1986, 198): 'each metaphor invites a view of learners who go through journeys that involve insecure, transitional states before mastery. ... Learning in the ZPD is not linear and incremental but involves recursive movements ... threshold concept mastery involves oscillating states.' However, there are fundamental differences which make any such analogy likely to be superficial because the ZPD is a pedagogical construct bounded by teacher assessments of the learner's level of achievement with or without help; liminality is the period during which the learner experiences the transformation of understanding inherent in learning a threshold concept.

Liminality can represent a formidable barrier. ‘Students can sometimes struggle to cope’ (Land *et al.* 2014, 1). Learners may experience 'ambiguity and incoherence' and 'doubt and uncertainty' (Hawkins and Edwards 2015, 28). From outside the threshold concepts literature, Burbules (2000, 173) describes what he calls ‘aporia’ as 'a crisis of choice, of action and identity, and not only of belief'.

On the other hand, transformative learning occurs within liminality. Predating threshold concept scholarship, Dewey (1910, 2 - 9) thought that 'a state of perplexity, hesitation, doubt' was the genesis of ‘reflective learning’ which was the only type of learning that he saw as 'truly educative'.

The liminal period is an opportunity for creative thinking (for example, Wisker 2007, 422; Maksimovic 2015), and for personal transformation (for example, Rattray 2014b). This may explain why Land *et al.* (2014b, 2) found that the teachers at an art college wanted their learners to stay in an ‘almost perpetual liminal state of creativity’ to keep their ‘thinking and practice … emergent and fresh’.

However there is little clarity about the details of liminality. Land *et al.* (2016, xvii) have described liminality as 'the ‘black box’ of thresholds research’; Savin-Baden (2008, 82) says, 'there are still questions to be asked about what happens in liminal spaces'. For example, liminality is described as a ‘state’ (for example, Meyer and Land 2006a; Sibbett and Thompson 2008, 236; Land *et al.* 2014b, 1; Land 2016) or a ‘space’ (Bradbeer 2005; Cousin 2006; Wisker 2007, 412; Savin-Baden 2008, 81; Wood 2012, 86; Allen 2014, 32; Ryan and Gass 2017) or a ‘zone’ (Mudge 2014, 62) or a ‘period’ (McCartney *et al.* 2009, 383; Schwartzman 2010, 42) or a ‘process’

(Wood 2012, 86) or a ‘lengthy tunnel’ (Harlow *et al.* 2011) or ‘a kind of no man’s land ... a labyrinth or maze’ (Rattray 2016, 71) or ‘a kind of flux’, ‘a creative space’, ‘a provisional, exploratory space’, ‘a space of emergence’, a ‘connected network’, a ‘tunnel’ and ‘a period of conceptual uncertainty’ (all Land *et al.* 2014b).

It can be argued that it was the dearth of detail from previous educational theorists that led the early threshold concept scholars to reach for metaphor and to seek an understanding of liminality from disciplines outside learning. Metaphors for liminality are drawn from a range of backgrounds including anthropology (Meyer and Land 2005 referring to the work of van Gennep 1960, and Turner 1995), Greek myth (Meyer and Land 2003 citing Palmer 2001), and Gothic fiction (Wisker 2007). For Conroy and Davis (2002, 261) teachers-as-tricksters inhabit a liminal borderland. Mudge (2014, 532) describes liminality as a ‘crossing frontiers’ experience in which ‘many students are indeed “without a map” both before and during the transition time.’ Hawkins and Edwards (2015, 35 - 36) envisage the teacher as ‘the master of ceremonies of liminal spaces ... a spirit guide ... or “sensei”’, which, as with Carmichael (2014, 26), links transformation to religious conversion.

Liminality is associated with being stuck (for example, Meyer and Land 2005, 377; Wisker and Savin-Baden 2009; Allen 2014), with oscillation (for example, Meyer and Land 2005, 376; Land et al 2014b; Mudge 2014, 53) and with mimicry (for example, Meyer and Land 2006b, 24; Land et al 2014b; Syed Mohammed *et al.* 2016, 83). However, none of these associated features are well-defined; again metaphors prevail. For example, oscillation is exemplified by discussing adolescence. This wide and eclectic harvesting of metaphors seems to mask an underdeveloped

theorisation. Out of a total of 1677 papers on the Threshold Concept bibliography maintained by Flanagan (2017) there were only 13 mentions of stuckness, three of mimicry (all from the same author) and none of oscillation. On the more than 13,000 strong key word index there were only seven mentions of stuck or stuckness, one of oscillating, and mimicry was not listed.

These and other aspects of liminality are explored below.

2.5.1: Learning in liminality is lonely

The social constructionist perspective is that meaning is constructed with other people; this has been briefly explored above in section 2.1.3. Outside the threshold concepts literature, a number of theorists propose this view of learning. Vygotsky, for example, believes that learning takes place in a social setting (Vygotsky and Kozulin 1986, 115). Manovich (2005) believes that knowledge is collaboratively constructed through multiple dialogues, as at a party. Driver, Asoko *et al.* (1994, 6) point out, the things that are being learned are socially constructed: the concepts of science ‘are not revealed in an obvious way by reading the book of nature. Rather, they are constructs that have been invented and imposed on phenomena in attempts to interpret and explain them’.

Nevertheless, Driver *et al.* (1985, 2) point out, different people get different things from ‘attending the same lecture or reading the same book ... Individuals internalise the experience in a way which is at least partially their own; they construct their own meanings’. Shymansky *et al.* (1997, 571) agree: 'meaningful learning requires a

personal restructuring of one's conceptual framework'. Barnett (2007, 63) asserts that 'no matter the extent of interaction with others, of dialogue or of collaboration, still the student's development, anxiety and becoming are hers, and hers alone.' In a review of models of knowledge creation, Paavola *et al.* (2004, 565) point out that although 'innovation processes are fundamentally social, individual activity also is emphasized'.

In the threshold concepts literature there is never any suggestion other than that a student journeys through liminality alone. Although the circumstances surrounding liminality, such as a rite of passage (Meyer and Land 2005, 375) or a classroom, are likely to involve more than one person, the experience of liminality is always individual and the hoped-for transformation is always personal.

2.5.2: Are there separate phases of liminality?

Meyer and Land (2005, 375) derived their notion of liminality from ethnographic work on initiation rituals, one of which (Van Gennep 1960, 11) divides a rite of passage into three parts: 'preliminal rites (rites of separation), liminal rites (rites of transition), and postliminal rites (rites of incorporation)'.These three phases are adopted into a number of threshold concept papers such as those by Akkaraju (2016, 29), Land and Meyer (2010, 61), and Kabo and Baillie (2010, 308).

In the first preliminal phase, discussed in more detail below in section 2.5.3, 'the established way of thinking dominates' (Baillie *et al.* 2010, 240) until 'troublesome knowledge' instigates or provokes (Land *et al.* 2010, xi) a 'disjunction' (Savin-Baden

2017, 11) or a ‘rupture ... accompanied by the shock of *estrangement*’ (Schwartzman 2010, 33 - 35) which leads to a separation from the old way of thinking (Hawkins and Edwards 2015, 26).

The second phase, the liminal, is ‘when the balance is changing’ (Baillie *et al.* 2013, 240). It is a time of transition (Hawkins and Edwards 2015, 26) when the learner feels ‘confused, stuck and frustrated’ (Savin-Baden 2017, 11). This is when ‘an integration of new knowledge occur which requires a reconfiguring of the learner’s prior conceptual schema and a letting go or discarding of any earlier conceptual stance.’ (Land *et al.* 2010, xi). This is accomplished through ‘taking on the challenge of uncertainty and its effective components by engaging with the unknown as unknown’ and examining the meaning-frame (Schwartzman 2010, 35).

The final phase, ‘when the new way of seeing has been adopted’ (Baillie *et al.* 2013, 240) is called postliminal. The transformation which has occurred is an ‘ontological shift’ (Savin-Baden 2017, 11). ‘The learner crosses a conceptual boundary into a new conceptual space’ (Land *et al.* 2010, xi). They reincorporate their new identity within the new context (Hawkins and Edwards 2015, 26).

The details within this apparently consensus view of a three part process of transformative learning through liminality suggest that this is more than a structure with a beginning, a middle, and an end imposed on a seamless experience. However the consensus fails when analysing the explanations for and implications of these descriptive details. For example, why are ‘estrangement’ and ‘separation’ in the preliminal phase whilst ‘letting go’ occurs in the liminal stage? Similarly, in what ways

is the liminal ‘integration of new knowledge’ different from the postliminal ‘incorporation’ or ‘reincorporation’?

The tripartite structure is found elsewhere. For example, Fortune *et al.* (2014, 57) explicitly link the journey of a student with a model of the way epic stories are structured; here the three phases are Departure, Initiation and Return. Outside threshold concept scholarship Kuhn (1996, 52 - 53) suggests a tripartite division in his analysis of scientific paradigm change: awareness, exploration, and adjustment. Seifert *et al.* (1996, 110 - 118), studying how eminent creative people achieve breakthrough thinking, also suggest a three stage process. The first stage is an initial grappling with the problem which ends in stuckness; in the second stage the problem remains at the back of the solver’s mind; the third stage is of reinterpretation and restructuring.

Land (2010, xi) offers the caveat that ‘the acquisition of threshold concepts often involves a degree of recursiveness, and of oscillation’ implying that the three stages described above are an outline and that the learner’s journey is less straightforward than the analysis above suggests. Once again the threshold concept literature can only take us so far and in considering the separation of the phases of liminality the literature outside the threshold concepts corpus offers little help. An empirical investigation is suggested.

2.5.3: Encountering the threshold

For the moment, however, features of transformation through liminality will be further explored through the literature.

Both threshold concept and concept change learning theorists envisage restructuring/ transformational learning as being triggered by a perceived incoherence between the material that is to be learned and the learner's prior knowledge. This causes the 'disorienting dilemma' (Mezirow 1990, 13) which has been described in section 2.4.3.

For Land *et al.* (2010, xi) it is troublesome knowledge that acts as 'an instigative or provocative feature which unsettles prior understanding rendering it fluid, and provoking a state of liminality.' Land and Meyer (2010, 63) point out that 'troublesomeness and disquietude is purposeful, as it is the provoker of change that cannot initially be assimilated, and hence is the instigator of new learning and new ontological possibility'. Threshold concept theorist Schwartzman (2010, 33) suggests that 'an anomaly that cannot be avoided' will lead to 'a rupture in knowing' which is caused by 'troublesome knowledge', defined as 'an anomaly that cannot be avoided, ignored, or made to conform'. Lucas and Mladenovic (2007, 240) believe that 'a focus on misconceptions is a particularly good point of entry for the identification of threshold concepts'. Land (2016, 14) agrees: 'The process of transformation is often triggered through encountering dissonance.' Meyer and Timmermans (2016, 28) suggest using '"Troublesomeness" ... deliberately to provoke the condition of a liminal state'.

This idea, which Festinger (1957) calls ‘cognitive dissonance‘; D'Mello and Graesser (2012, 145) call ‘cognitive disequilibrium’; Berlyne (1960, 284 - 288) called ‘conceptual conflict’; Osgood and Tannenbaum (1955) called ‘incongruity’; and Heider (1946) called ‘imbalance’, also occurs in the literature outside the threshold concepts corpus. Concept change theorists such as Bao *et al.* (2013) identify cognitive conflict as ‘an important factor in conceptual change’. Vygotsky had already suggested that to initiate concept formation ‘a problem must arise that cannot be solved otherwise than through the formation of new concepts’ (Vygotsky and Kozulin 1986, 107); Ohisson and Cosejo (2014, 1490) make the point that ‘conceptual change is triggered by ... dissatisfaction with the current conception’; Gouge and Yates (2002, 134) suggest that Piagetian equilibration ‘occurs when the learner’s existing mental structures are challenged by cognitive demands which they cannot quite meet’; Carey (1991, 259) believes that one of the motivators for concept change is when ‘concepts are embedded in locally incommensurable theories’; Gopnik (2000, 311) believes that learning is triggered by the realisation of ‘an unsettling, disturbing and arousing experience’; Treagust and Duit (2009, 91) state that ‘student dissatisfaction with a prior conception was believed to initiate dramatic or revolutionary conceptual change’.

Many describe it as unpleasant. Dewey (1910, 74) suggested that reflective thinking was prompted by something ‘queer, strange, funny, or disconcerting’. Festinger (1957, 3) called dissonance ‘psychologically uncomfortable’. Elliot and Devine 1994 say that it causes ‘psychological discomfort’. D'Mello and Graesser (2012, 146) say that ‘confusion is a key signature of the cognitive disequilibrium.’ ‘Viewpoints that call

our frames of reference into question rnay be dismissed as distorting, deceptive, ill intentioned, or crazy' says Mezirow (2000, 18). This leads to a perspective that learning is caused because this inconsistency 'upsets us and it drives us to action' (Cooper 2007, 2) generating an arousal which the learner is driven to reduce (Ausubel and Robinson 1969, 363 – 364) or, more positively, motivating the learner to resolve the inconsistencies (Driver 1983, 52). Kunda (1990, 481) points out that people are prepared to tolerate a certain amount of discomfort because they balance it against the effort required to resolve the situation. However, as new evidence continues to build up it will become 'overwhelming'; at a certain point the learner will be unable to resist the pressures (Festinger 1957, 43).

How does the threshold 'come into view'? ask Meyer and Land (2005, 384). Sometimes it appears that learners fail to see a threshold presented to them. Carmichael (2014, 26) compares the liminal experience to the journey of the Pilgrim in Bunyan's *The Pilgrim's Progress* and points out that 'in the opening chapter of the book, the Pilgrim is not even sure he can see this particular portal and it becomes visible only once he has begun his journey.' When students 'showed little or no understanding' Kabo and Baillie (2010, 309) interpreted that 'at least some parts of the threshold had not come into view for them yet.' Pang and Meyer (2010, 365) and Meyer *et al.* (2008, 68) propose that differences between the prior knowledge of different learners might affect how they perceive a threshold as well as how they react to a threshold when perceived.

This is another fundamentally constructivist idea. As Driver, Squires *et al.* (1994, 7) puts it: 'When children look at phenomena, the sense that is made will be influenced

by their existing ideas'. Bell (2005, 63) asserts that 'observation is influenced strongly by the existing ideas of the student'; 'even if students are confronted with what appears to be contradictions to the teacher, they will not necessarily recognise them' (Driver *et al.* (1985, 2 - 5). Driver (1983, 45) suggested that this might be because they do not understand the new concepts: 'Before pupils can be expected to abandon their old ideas, they have at least to be able to comprehend the ones which are presented to them'. Ausubel and Robinson (1969, 124) point out that this means that what is learned may be different from what has been taught.

2.5.4: Threshold avoidance

Even if the learner perceives the threshold this might still be insufficient to instigate entrance into liminality. Festinger showed that changing schemata was rather more complicated than previously thought and Driver (1983, 52) acknowledges that although 'it is the need to resolve the cognitive dissonance that provides the intrinsic motivation for learning', cognitive dissonance may not be enough in itself. Fosnot and Perry (2005, 19 - 20) talked of a contradiction creating a transition zone which in turn led to one of three possible outcomes: ignore the contradiction, hold 'both theories simultaneously', or construct a new model. Other writers such as Abelson (1959, 343), Chinn and Brewer (1993), and Posner *et al.* (1982) list a number of ways in which a learner could react to anomalous data. Burbules (2000, 179) talks about the situations in which one might not know how to proceed: 'There is no path in sight ... there are too many paths from which to choose ... one cannot recognize a path that is already there ... the path is apparent, but one cannot or will not follow it (perhaps because the destination is unknown, perhaps because it is known and

unpleasant).' Atherton (2013) points out that there is a 'cost' involved for a learner in 'changing their ways' and that consideration of this might lead to a rational decision to avoid a threshold.

Threshold concept scholars suggest that, having seen a threshold, a learner might adopt strategies to avoid it. Meyer and Land (2006b, 30) suggest that a student who has seen a threshold portal might engage in learning strategies designed to avoid passing through the threshold, perhaps because of 'an active refusal of learning, or an anxiety about its transformative effects'. Schwartzman (2010, 34) suggests that 'defensiveness' is an alternate reaction to the reflection she sees as the foundation of learning when the learning is confronted with the sense of estrangement which comes with 'rupture'. Savin-Barden (2006, 163 - 165) lists three threshold avoidance strategies to the disjunction experienced as a reaction to the threshold concept: to 'retreat behind some form of excuse' or 'take up a particular position, entrench themselves within it, and then reinforce the bunkers around that position'; to temporise or 'acknowledge the existence of disjunction ... [but] postpone making any decision about how to manage it'; or to avoid the threshold by adopting 'mechanisms that will enable them to find some way of circumventing the disjunction'.

Concept change learning theorists also recognise that a response to a cognitive challenge might be to refuse to learn. As Smith *et al.* (1993) point out, confronting students with 'the correct ideas' implicitly devalues their prior knowledge. Their identity as successful learners may feel threatened; having felt competent they may now be made to feel incompetent. Lee *et al.* (2003, 587 - 590) suggest that 'contradictory information can be threatening ... if a student feels frustrated or

threatened ... conceptual conflict might be destructive.' Mezirow (1990, 4) points out that 'when experience is strange or threatening to the way we think or learn, we tend to block it out or resort to psychological defense mechanisms to provide a more compatible interpretation'. Zohar and Aharon-Kravetsky (2005) believe that cognitive challenge might benefit high ability but not low ability students' perhaps because of the difference in resilience between the groups; Bao *et al.* (2013), whilst recognising that 'only a small fraction of students experience high levels of anxiety during learning' and that in any case 'anxiety is not necessarily negative to learning' nevertheless found that most of those students who did experience high levels of anxiety tended 'to hold on to their existing understanding' rather than learning by modifying their conceptual networks.

There are benefits to a strategy of living with a certain level of conceptual challenge. Kunda (1990, 481) suggests that people take into account the mental effort likely to be needed when they are trying to resolve a conceptual dilemma and balance this against the discomfort provoked by the dilemma. It would not be possible to respond to every perceived inconsistency with a full scale restructuring of a concept network. Norman (1982, 8) suggests that our concept networks (he calls them 'mental models') are characteristically incomplete and unstable, without firm boundaries. Driver *et al.* (1985, 3) suggests that a child does not 'necessarily see the need for a coherent view, since *ad hoc* interpretations and predictions about natural events may appear to work quite well in practice.' Most if not all adults also have inconsistencies in our concept networks, 'dormant and unthought about' (Abelson 1959, 344). Collins *et al.* (1975) suggest that this helps us to cope with 'a world full of ambiguity and uncertainty'. It is not possible to pay attention to everything (for

example, Chow and Conway 2015); a scientist cannot explore every discrepant fact (Kuhn 1996, 82). Furthermore, given that every perception is interpreted within a conceptual framework (Hanson 1965, 19) it may be that the anomalies are simply incorrect. Driver, Asoko *et al.* (1994, 7) points out the likelihood that each of us has 'plural conceptual schemes, each appropriate to specific social settings'. Fosnot and Perry (2005, 20) suggest that learners can endeavour to hold two theories at the same time, switching from one to another as the context requires. For example, they may acknowledge the earth is spherical whilst treating it as flat (Vosniadou *et al.* 2008, 7) or accept Darwinian evolution for the science examination while rejecting it elsewhere (Gilbert *et al.* 1982, 252). Rocket scientists set aside Einstein's relativity to calculate flight paths using Newtonian mechanics (Weinberg 1987, 7). This last example shows that even after a concept network has been modified, a learner is still able to return to the previous conceptions, at least to some extent.

Once the learner has seen and acknowledged the threshold they pass through the threshold into the 'liquid space' of liminality (Meyer and Land 2005, 380).

2.5.5: Affective aspects of the liminal experience

Some of the affective aspects of the liminal experience have been noted above. Hawkins and Edwards (2015, 28) suggest that characteristics of the liminal experience include 'ambiguity and incoherence' and 'doubt and uncertainty'. Schwartman (2010, 34) describes 'estrangement and engendered unease and uncertainty.' Syed Mohammed *et al.* (2016, 86), studying military training, talk of ambivalence and hybridity (which is defined as 'simultaneous conflicting reactions'). For Mudge (2014, 55) liminality is a feeling of disorientation, 'an experience of exile

and pain'. Rattray (2016, 71) describes liminality as 'a dark and foreboding place'. Allen (2014, 33) talks about 'disequilibrium and uncertainty'; Keefer (2015, 18 - 23) of 'uncertainty, confusion, and lack of confidence'; he also identifies loneliness. Meyer and Land (2005, 376) see the liminal experience as '... often problematic, troubling and frequently involves the humbling of the participant'.

Outside the threshold concepts literature, other writers have described learning experiences that resonate with liminal experiences. Meno described Socrates as like a stingray: 'go near and touch one of those fish and you go numb' (Plato 1956). Dewey (1910, 73 - 74) described the first encounter with a difficulty as 'a shock, as emotional disturbance, as a more or less vague feeling of the unexpected, of something queer, strange, funny or disconcerting' he believed that thought started with 'perplexity, confusion, doubt' (Dewey 1926, 176). D'Mello and Graesser (2012, 146) describe what they call cognitive disequilibrium as 'a state of uncertainty that occurs when an individual is confronted with obstacles to goals, interruptions of organized action sequences, impasses, contradictions, anomalous events, dissonance, incongruities, unexpected feedback, uncertainty, deviations from norms, and novelty.' Movshovitz-Hadar and Hadass (1990) confronted undergraduates on a Mathematics Education programme with paradox, a type of cognitive challenge, and elicited comments which suggested that the learners felt 'stupid', 'ridiculous', 'threatened', 'helpless', 'betrayed' and 'irritated'. Hansen and Laverty (2010, 226) say that 'real learning often entails tension, anxiety, moments of uncertainty, and the disconfirmation of expectations.' Transformational learning is an experience analogous to crisis according to Atherton (1999). Hodgkin (1976, 11) talks about the

frontier of an individual's knowledge beyond which lie 'conflicts, threats, problems, difficulties and unknown allurements.'

On the other hand Timmermans (2010, 12) points out that not everyone will feel the same way. 'When standing on the edge of a cliff (or a threshold), might not some learners feel terror, while others feel exhilaration?' Nevertheless, the overwhelming consensus is that this sort of learning is, perhaps necessarily, unpleasant. Myers (2010, 19) points out: 'if the new concept is supposed to modify or replace the structure of what you already know, that's when it hurts'.

2.5.6: Can liminality aid learning?

Some theorists suggest that liminality is beneficial to learning; it may even be essential to learning. Learning is about making connections and Harlow *et al.* (2014; p 67) believe that this is what happens as a learner travels through the liminal experience. In an autoethnography of doing a PhD, Maksimovic (2015) calls the liminal space a '*fertile void*' where 'there is a space for learning and creation.' Hawkins and Edwards (2015, 27) suggest that the liminal experience allows learners to try things out. Liminality allows creativity (Land *et al.* 2014b, 2). 'Disorder and chaos can be fruitful in that new ideas and forms can emerge from it' (Bigger 2010, 3). Mudge (2014, 62) concurs: 'Confusion, fuzziness or lack of clear answers is sometimes beneficial to both the thinking and learning processes.'

Similar ideas are found from writers outside threshold concept scholarship. Dewey (1910, 118) described seeing a stone with odd scratches on it and thought that 'it is such peculiar combinations of the understood and the nonunderstood that provoke

thought.' Kounios and Beeman (2009, 210) believe that 'because insight involves a conceptual reorganization that results in a new, nonobvious interpretation, it is often identified as a form of creativity'. Johansson *et al.* (2014, 609) suggest that it is not until order breaks that change becomes possible. The 'experience of impossibility' states Lather (1998**,** 495) is developed by liminality. The liminal experience enables what Locke *et al.* (2008, 909) call musement, the 'a-critical generation and exploration of ideas'. Seale (1999, 33) suggests that 'episodes of anarchic thinking can help to generate creative insights'. Cook (2009), who describes the liminal space as a 'messy area', which she equates with the 'punctum' of Barthes (1984, 40 – 59), believes that 'the purpose of mess is to facilitate a turn towards new constructions of knowing'.

2.5.7: Stuckness

One of the reasons that liminality hurts is that learners often get stuck. Wisker (2014) suggests that doctoral students who get stuck 'report silencing, loss of confidence and paralysis in their work.' All the issues described above that confront a learner at the threshold, which might make them reluctant to pass through the threshold and enter liminality, might continue to apply whilst the learner undergoes the liminal experience. Savin-Baden (2008, 81) also suggests there are more than one kind of disjunction, a word she seems to use as an alternative or a synonym to stuckness: 'a little bit like hitting a brick wall in learning' or 'a sense of vague stuckness, a feeling of confusion or an idea that one has come across some difficulty or troublesomeness but what that is, is not entirely clear'. Flanagan and Smith (2008, 98) describe stuckness as 'perplexity, even paralysis'. There are clear resonances here with Burbules (2000) talking from outside the threshold concept tradition about different

types of doubt. One is ‘the empty pause, the frozen, paralyzed instant ... a moment of futility and embarrassment’. The second is ‘to be stymied, to be delayed, to be stuck, in between ... there are too many choices, and one does not know how to recognize the path or paths that will help one to pass through’. In both cases ‘I'm stuck. I don't know how to go on’.

2.5.8: Oscillation

Another of the hallmarks of liminality is oscillation. Booth (2006, 177) sees oscillation as characteristic of the liminal state. Quinnell *et al.* (2014, 4) suggest that some learners need to ‘make the same transition several times (a degree of wobbliness) before finally crossing the liminal space.’

It is not always clear what learners oscillate in between: for Jazvac-Martek (2009, 258) the oscillation is between roles whilst for Keefer (2015, 20) it is ‘between student and academic identities’. Land *et al.* (2014a, 201) state that ‘learning within the liminal state is sometimes experienced as oscillative, as the changed perspective slips in out of focus and eludes the learner's grasp.’ Land *et al.* (2006, 196) describe liminality as ‘an ‘in-between’ state ... in which they [students] oscillate between earlier, less sophisticated understandings, and the fuller appreciation of a concept’. Savin-Baden (2017, 6) characterizes liminality ‘by a stripping away of old identities and an oscillation between states’. Orsini-Jones (2008, 218 - 219) observed students oscillating between the pre-liminal and the post-liminal state. Mudge (2014, 53) defines liminality itself as ‘messy back and forth journeys’ over the threshold and Keefer (2015, 19) suggests that ‘liminality involves wavering between two worlds’.

Baillie *et al.* (2013, 240) describe oscillation as ‘an ebb and flow of understanding’. Thomas *et al.* (2010, 245) described students ‘going back and forth between knowing and not knowing’ although the only evidence published was the testimony of a respondent who said: ‘it just seemed to me like while I was in the thick of it I would forget. I spent a lot of time lost in the - it was that forest for the trees. I don’t know. Lost in the jungle’ which does not appear to describe oscillation.

These characterise oscillation as inevitable but problematic. Rather than achieving transformative understanding immediately, learners often need to have more than one attempt.

But other threshold concept scholars seem to view oscillation as an important (perhaps non-deliberative) strategy that improves learning by taking account of different points of view. Thus Wood (2012) appears to suggest that oscillation enhances learning when stating that ‘students are seen to move in and out of liminal spaces thereby allowing shifts in perspective and the addition of extra experiences to be brought to bear on the liminal process.’ Orsini-Jones (2010, 282) agrees, drawing a distinction between oscillation and stuckness when writing that ‘students who become “stuck” on the “pre-liminal” position ... lack the flexibility necessary to oscillate in the liminal state.’ Kinchin *et al.* (2010, 88), observing text analysis seminars, note that a student ‘has to be able to oscillate purposefully between text and social background.’ Easdown (2014, 48) asserts that ‘naturally oscillatory or recursive behaviour ... typifies successful movement between pre-liminal and liminal phases’. Hokstad *et al.* (2016, 326) suggest that ‘the liminal stage is characterized by the students’ lack of ability to oscillate between different perspectives’ which

prevents understanding although they also see oscillation as descriptive of an ‘iterative and recursive’ characteristic of liminality involving ‘false victory and defeat’.

Oscillation is thus a concept with a diversity of sometimes apparently contradictory meanings. This suggests that it is poorly understood. Evidence for oscillation was therefore sought in literature outside threshold concepts scholarship. Vygotsky (Vygotsky and Kozulin, 2011, 204) asked whether intellectual functions mature as ‘a sudden ‘shot’ or as a slow process that has both leaps and zigzags?’ Berlyne (1960, 122) described animals oscillating between fear and curiosity. There is evidence of oscillation from the history of science as well: one of the key thresholds that Isaac Newton had to pass in order to develop his Laws of Motion was to recognize that the mediaeval idea of impetus, a force inherent within a body, was incorrect. Steinberg *et al.* (1990, 267 - 268) show that he first recognised this around 1665 and yet he was still reverting to internal forces in 1684. Kneller (1965, 47 - 57) studying the four phases of creativity suggests that a creator often wanders to and fro between the first two stages of preparation and incubation. Burbules and Linn (1991, 235) describe oscillation as conceptual wandering in terms of ‘switching back and forth between incompatible hypotheses’.

Oscillation is therefore a concept with wide recognition but very little clarity. To understand it better it was decided to seek examples of oscillation empirically. Oscillation is therefore one of the research targets of the empirical stage of this investigation.

2.5.9: Mimicry

Threshold concept scholars consider any alternatives to passing through the threshold will lead to something they call ‘mimicry’: a student ‘having glimpsed the outline of a threshold portal and perhaps only vaguely aware of what lies beyond it, but conscious of the failure to cross it, may engage in ... mimicry’ (Meyer and Land 2006b, 24). Mimicry, it is suggested, can be a deliberate attempt to avoid the threshold (Allen 2014, 33). Meyer and Land (2005, 381) report work by Williamson (1992) who suggested that males studying sexism ‘can bypass an interrogation of their own masculinity’ and at the same time ‘churn out dutiful assessment assignments that attract good marks’; they report Cousin (2003) also finding learners ‘‘bypassing’ or ‘faking it’. Atherton (2013) describes adult learners keeping knowledge ‘sealed off’ as ‘academic’ so that it doesn’t have to impinge upon their professional practice. Thomas *et al.* (2017, 343) claim evidence for mimicry in an analysis of the responses of computer science students. Cousin (2006a, 5) recognises that mimicry may be a temporarily useful strategy but warns that it might lead to a learning that is ‘the product of ritualised performances rather than integrated understandings.’ Alternatively, mimicry may involve a genuine but unsuccessful attempt on the part of the learner, ‘a serious attempt to come to terms with conceptual difficulty, or to try on certain conceptual novelties for size as it were’ (Meyer and Land 2005, 381); ‘both attempts at understanding and troubled misunderstanding, or limited understanding’ (Meyer and Land 2005, 377); ‘a cosmetic grasp of the concept they have by no means mastered’ (Booth 2006, 177).

Syed Mohammed *et al.* (2016, 83) link mimicry to notions of ambivalence (‘having simultaneous conflicting reactions, beliefs, or feelings towards knowledge deemed

troublesome as a result of previously held beliefs') in which a learner may act as if they had passed through the threshold without identifying as someone who has passed through the threshold. This may be linked to the 'imposter syndrome of not being good enough' identified by Keefer (2015, 23) in a study of research students studying towards doctorates.

2.6: Summary

Threshold concept scholarship combines the ontologically realist notion of the 'threshold concept' with the epistemologically and pedagogically constructivist notion of learning by transformation in liminality. It has been argued above that such a philosophical pairing is not incompatible and is indeed similar to that found in both physics and education which are the contexts for this study.

The notion of liminality, the period during which the transformation takes place, marks an important advance in constructivist theories of learning. Therefore the concepts of transformation and liminality were considered in focused detail. Where necessary, sources outside the threshold concept literature were consulted.

The transformation is sometimes understood as a reconfiguration of a learner's knowledge and sometimes as transformation of a learner's 'identity' or 'ontology' or 'subjectivity'. The transformation is instigated by a cognitive challenge which causes the learner to pass through the threshold and enter the liminal experience unless the learner employs a threshold avoidance strategy.

The transformation within liminality begins with loss. Liminality is characterised by doubt and uncertainty; it involves a creative chaos of ideas. Characteristics of liminality involve stuckness and oscillation and mimicry. At some point (it is hoped) there is a transformative reintegration of ideas. This process can take time but is more often viewed as sudden which resonates with the ‘eureka’ effect.

However, there are many aspects of this process that are unclear or ambiguous or contested. Although knowledge reconfiguration and identity transformation are not mutually exclusive (as Cousin 2006a, 4, asserts, ‘we are what we know’) the differing discourses suggest a vagueness about what is being transformed. Similarly the mechanics of transformation, how it occurs, are insufficiently developed.

There is a consensus that liminality is something experienced on an individual basis and that it has a before phase in which a cognitive challenge instigates liminality, a during phase and an after phase although there is some disagreement about the details of what happens in each phase. There is a diversity of opinion about why some learners adopt threshold avoidance strategies, choosing mimicry instead. There is agreement that one of the characteristics of liminality is stuckness but there is a clear division between those who see oscillation as being a negative consequence of uncertainty and those who view it as an essential flexibility.

Much of the evidence is anecdotal and appears to be based on the writer reflecting on their own experience. Where evidence has been collected from others this also tends to be of a *post hoc*, reflective nature. It is proposed that, in order to clarify

some of the characteristics described above it is necessary to observe learners in the act of learning through transformation in liminality.

2.7: Research questions

It is clear from the summary that there are many aspects of the liminal experience which are undecided following the literature review. These will therefore form the research questions for the empirical phase of this study.

What are the characteristics of learning transformation?

What are the characteristics of liminality?

How does a learner enter liminality?

What is the relationship between transformation, liminality and learning?

How can knowledge and understanding of the relationship between transformation, liminality and learning improve the teaching of secondary school physics?

Chapter 3: Methodology and Method

3.1: Characteristics of Study

Jones *et al.* (2006, 32) liken research to a journey in which the epistemology is the territory, the theoretical perspective is the map, the 'specific routes to take' is the methodology and the method is the 'mode of transportation'. They follow Crotty (1998, 3) in suggesting that this means that a researcher needs to make four choices, in sequence: epistemology, theoretical perspective, methodology, and method. Each of these decisions needed to be considered in the light of the characteristics of the study. The aim is to ensure coherence.

The critique of the literature had concluded that the core of threshold concept scholarship was under-theorised. Schwartzman (2010, 29) suggests that 'the search for a theoretical foundation ... explores how students actually do respond to existentially unfamiliar, educationally critical material within a discipline.' Hence, it was decided to seek empirical evidence to improve the clarity of some of the central notions. This means that the fundamental characteristic of this study is that it is exploratory. Given the lack of clear theory to test or to critique, it is inappropriate either to create testable hypotheses in a Popperian hypothetico-deductive style, or to employ a critical inquiry approach at this stage.

Schwartzman (2010, 27) asserts that there are two ways of considering learning: 'what it means to have learned; or how learning happens.' She points out that four of

the five original characteristics for identifying threshold concepts described the aftermath of (successful) learning and the fifth, troublesomeness, described the material to be learned. This prompts the gathering of evidence from before learning to compare with that gathered after learning. Many of the empirically-based studies reported in the literature use *post-hoc* reflection. But my study focused on learning as transformation within liminality, 'how learning happens' in Schwartzman's terms. For this evidence needs to be collected in real-time from learners as they engage in learning. This suggested an observational study.

As a teacher, I had observed many students experiencing stuckness and confusion while learning physics. The literature suggested that physics possessed a rich source of stimuli for initiating liminality. This was therefore considered an appropriate context for studying liminality.

3.2: The epistemology within which this study is located

Epistemology is 'the theory of knowledge' (Crotty 1998, 3) which determines 'what we know and how we know it' (Dupre 2007, 7), providing the 'criteria by which valid knowledge about a phenomenon may be constructed and evaluated' (Orlikowski and Baroudi 1991, 8). Jones *et al.* (2006, 39) argues that the epistemology, the methodology and the theoretical perspective need to be congruent. Mills *et al.* (2006, 26) asserts that 'to ensure a strong research design, researchers must choose a research paradigm that is congruent with their beliefs about the nature of reality'. A methodology that was dissonant with the epistemological underpinning of the object of the study would lead to a fundamental incoherence within the study.

In chapter two the argument was made that in the early years of the twentieth century both physics and teaching were reinterpreted from a constructivist perspective. As constructivism became the dominant discourse in the second half of the century it shaped concept change theory which is ‘embedded in radical constructivist epistemological views’ (Duit and Treagust 2004, 58). It was argued that threshold concept scholarship developed within this fundamentally constructivist perspective; although the notion of the ‘threshold concept’ itself is ontologically realist the concept that learning is transformation within liminality is both epistemologically and pedagogically constructivist.

3.3: Theoretical perspectives

Since, as argued above, both the focus of this study and the context employ a constructivist epistemology, the principles of congruence suggest employing a methodology that is compatible with constructivism. This excludes a positivist perspective but might encompass postpositivism as well as interpretivist perspectives such as symbolic interactionism, phenomenology, and hermeneutics. It is argued that the realist ontology of threshold concepts presents an obstacle to the adoption of a postmodern perspective.

The criteria for choosing the best-fit perspective included: whether the data and/or its analysis is quantitative or qualitative; whether the study’s perspective is emic or etic; whether the research is idiographic (focused on the individual) or nomothetic

(seeking general patterns); to what extent is the aim to understand liminality or to enable better (or different) learning; to what extent the data and the results can be regarded as objective (within limits imposed by accuracy, reliability and validity etc) or as interpretive; whether the intention is to describe liminality or to explain the factors affecting it, or to use a previously identified perspective to interpret the data?

3.3.1: Quantitative versus Qualitative

The two aspects of the qualitative quantitative dichotomy to be considered are the nature of the data and how it would be analysed. Counting word frequencies, for example, is a quantitative analysis of qualitative data.

The literature review shows that most of the research on threshold concepts, and particularly on liminality, has been qualitative. Furthermore, the research was exploratory and Creswell (2003, 22) states that ‘qualitative research is exploratory and is useful when the researcher does not know the important variables to examine’. Also the second research question focuses on the experience of liminality; Strauss and Corbin (1998, 11) recommend ‘qualitative methods ... to obtain the intricate details about phenomena such as feelings’.

After the first interview it was realised that there were aspects of the research (such as pause lengths) that merited quantitative analysis. Nevertheless my approach to the data was predominantly qualitative and required interpretation which suggested locating the research within an interpretivist perspective as, according to Brannen (2005, 7), is typical of qualitative research.

3.3.2: Emic or etic

To date, threshold concept scholarship has largely adopted an etic perspective; that is from the perspective of the teachers rather than from that of the learners although the learners are the ones passing through the threshold. The third research question positions this research as emic, studied from the insider perspective. This perspective is difficult to accommodate in positivist and postpositivist approaches. This was another argument in favour of an interpretivist approach.

3.3.3: Idiographic or nomothetic

According to Taber (2000, 469), educational research is either idiographic (focused on the individual) or nomothetic (seeking general patterns); interpretivist perspectives tend to be idiographic.

On the one hand, threshold concept scholarship is about developing curricula, which involves treating learners in terms of their group characteristics, for example asking which concepts in a programme of study will act as a threshold for all or most of the learners. But there is also an acknowledgement that, particularly when it comes to liminality, learners are ‘unique’ (Zepke 2013, 103). Meyer and Land (2005, 381) believe that the threshold concept lens enables a ‘critical micro-perspective level within the epistemology of the discipline’; which foregrounds student variation. Land *et al.* (2006, 203) explicitly build ‘preliminal variation’ into the design considerations when building a course, asking how does the threshold ‘“come into view” for individual students?’. Meyer and Timmermans (2016, 30) suggest a predisposition

towards ‘the contextualised learning experiences of “real people”’ and so recommend ‘phenomenographic analysis.’

Although this research was focussed on the individual, and there was every expectation that a research question about how it felt to experience liminality would elicit individualised responses, nevertheless there was a presupposition that general trends might emerge. This was an argument in favour of finding a methodology that could achieve an appropriate balance between an idiographic data collection and the drawing of potentially nomothetic conclusions. This positioned it nearest to an interpretivist theoretical perspective.

3.3.4: Purpose of study

Crotty (1998, 113) distinguishes between ‘a research that seeks merely to understand and a research that challenges’. Many interpretivist perspectives seek to understand as opposed to critical inquiry approaches which seek to challenge and change the *status quo*. For example, Esterberg (2002, 17) states that ‘critical social research ... seeks insight into the social world in order to help people change oppressive social conditions’ and Newby (2014, 43) asserts that ‘all critical theorists ... seek not just to explain but also to change.’ According to Locke *et al.* (2009, 194) one of the assumptions underlying critical research is that the researcher must ‘be concerned with how knowledge is used and, particularly, how that use relates to inequities in the distribution of power and material resources in our society’ and Robson (2002, 28) suggests, that approaches such as critical inquiry are fundamentally ‘emancipatory’ and concerned to show ‘how and why ... inequities are reflected in asymmetric power relationships’. Jones *et al.* (2006, 41) suggest, critical

theory has ‘an emphasis on emancipation’; it is ‘propagated with the idea that it will itself be the catalytic agent in the overthrow of a given social order’ (Fay 1993, 34). ‘Critical pedagogical researchers often regard their work as a first step toward forms of political action that can redress the injustices found’ (Kincheloe *et al.* 2011, 167).

Given the educational context of this research it is anticipated that the results might lead to better teaching and the last research question asks about the relationship between liminality and learning. Nevertheless, the primary purpose of the research was to understand the liminal experience better as evidenced by the other research questions. Because of this, it was considered that a critical inquiry approach would be inappropriate for this study.

There was a further argument. Although Land (2016, 16 - 19) had already presaged the idea of a critical inquiry approach to threshold concepts when he called for a ‘pedagogy of uncertainty’ to safeguard the ‘transformative approach to learning’ against the expected inroads from the ‘neoliberal rendering of the learner as consumer of educational services’ there was a suspicion that the current understanding of liminality was insufficiently clarified to develop a point of view from which to formulate a critical perspective. Therefore the critical inquiry approach was rejected.

3.3.5: Objectivity of data and results

It has been argued above that much of the data is interpretive. This is true even of quantitative data: knowing how long a pause lasts does not establish what the pause ‘means’.

Given the lack of clarity surrounding the concepts of liminality, stuckness, oscillation and mimicry and the consequent exploratory nature of the study it was expected that the results would not be what Crotty (1998, 41) calls ‘established fact’. Furthermore, a high degree of context dependence was expected because of the concept of preliminal variation. This was another reason for rejecting a postpositivist perspective. On the other hand, theoretical perspectives in which context is regarded as fundamentally important, such as hermeneutics, grounded theory, and postmodernism, remained contenders for possible theoretical perspectives for this study.

There are aspects of the literature on liminality which might be regarded as postmodern. Meyer and Land (2003; 2005) draw ideas about liminality from a variety of perspectives including anthropology, classical studies and pedagogy. Esterberg (2002, 16) suggests that ‘a variety of competing perspectives, ... a number of different realities and ways of knowing, all equally valid’ is a characteristic of postmodernism. This means that a researcher’s interpretation might do ‘violence’ to what an interviewee might mean (Foster and Parker 1995, 105). Newby (2014, 44) concurs: ‘Postmodernism rejects the assumption of a single explanation of things ... and recognises that the world is a complex place that is full of contradictions.’ However, the direction of this study was intended to be towards clarifying the concepts of liminality and its associates and this implied travelling towards fewer perspectives. So did the desire for a conclusion that was, at least to some extent, nomothetic. This ruled out a postmodernist perspective to the inquiry.

3.3.6: Best fit theoretical perspective

In summary, a consideration of the characteristics of the study has narrowed the theoretical perspective field. Postpositivism was rejected because of the preponderance of qualitative data, the idiographic nature of the data, and the desire to interpret the results from an emic perspective. Critical inquiry had been excluded because the intention of the study was to understand rather than challenge. Postmodernism had been dismissed because the intent was to narrow the focus rather than to fragment the perspective and because of the ontologically realist aspect of threshold concepts.

The best-fit theoretical perspective was therefore interpretivist. I considered three interpretivist methodologies: action research because it has a strong tradition in education, ethnography because of the potential importance of context, and grounded theory because its methodology of seeking to develop theory from data resonated with my aims.

3.4: Methodologies

3.4.1: Action research

There is a tradition of action research in education. It has also been used successfully in threshold concepts scholarship. For example, Harlow *et al.* (2017) use action research to evaluate the implementation of a programme of identifying threshold concepts to help lecturers improve undergraduate teaching courses. Also,

Orsini-Jones (2010) used action research to evaluate the effect on student performance of pedagogical adjustments made having identified a threshold concept. These examples evidence the characterisation of action research by Denscombe (2007, 123): that it is practical, it seeks to cause a change, it operates as part of a cyclic process and that it involves the active participation of those studied. In action research the researcher intervenes in the setting in order to produce a change (which makes it ideal for a critical perspective according to Esterberg 2002, 34) and then relates the observed effects of the change to the postulated causes.

Much action research involves a pre and post-test design. This was rejected because, as argued in section 3.1, the intention was to observe the learner in the process of learning. But alternative action research designs were still possible.

The strength of action research lies in comparing the performance of learners under the condition of a particular learning strategy with the performance of a group under alternative conditions. However, in the case of this research it was contended that learning as transformation within liminality was not yet sufficiently well theorised to be able to formulate learning strategies.

Furthermore, action research is usually intended to produce an improvement in something but it was not clear what the criteria for improvement would be in this context. It is possible that some of the dimensions of liminality are entangled. For example, a particular strategy might reduce the time spent in liminality and make the

experience less unpleasant but at the same time might reduce the effectiveness of the learning.

For these reasons action research was rejected as a methodology.

3.4.2: Ethnography

Stern (1994, 215) suggests that ethnographers ‘approach the field armed with theory’. Given that the purpose of this research was to develop theory this seemed to rule out an ethnographic approach. However, Denscombe (2007, 67 - 69) states that other ethnographers are describers rather than theory testers and suggests that ethnographers overcome their preconceptions by exploring how ‘the researcher’s identity, values and beliefs become part of the equation’. This meant that ethnography was still available for consideration.

On the other hand Esterberg (2002, 58) suggests that ‘participant observation’ is a key characteristic of ethnography and Boyle (1994, 163) recommends that the researcher takes the role of an apprentice within the group so that their participant status of learner reflects what they are actually trying to do. I desired to investigate the learning experiences of learners aged 17 and 18; as a man in his late 50s I could scarcely pass myself off as a participant, let alone as an apprentice.

Jones *et al.* (2006, 57) say that the characteristics of ethnography are ‘immersion in a particular setting, prolonged engagement and relationship building, and the

generation of *thick description*'. The typical student at the level I was investigating studies physics in class for about five hours per week for about 36 weeks in a year. A maximum of 180 hours of observation per year would not be sufficiently prolonged to enable immersion and thick description.

It was suggested that I considered my own process of working for a research degree as an extended liminal experience and that I created an auto-ethnography similar to that produced by Maksimovic (2015). I rejected this approach because reflective enquiry of any kind is susceptible to bias from unrecognised pre-judgements. For example, Ross (2014, 220) 'challenges the notion that reflective writing is ever authentic' because of 'awareness of audience'. Whilst recognising the impossibility of eliminating bias I was seeking to reduce bias. A second reason for rejecting auto-ethnography was that within the threshold concept literature there were already a number of papers in which the characteristics of learning as transformation within liminality had been deduced from anecdotal reflections upon the experiences of the author(s) as learner or teacher. I was seeking to do something different. I therefore restricted the autoethnographic route to a supplementary perspective within the discussion.

For these primarily practical reasons I rejected an ethnographic approach.

3.4.3: Grounded theory

Fernyhough (2017, 29) suggests that early research into a topic should be aimed at ‘establishing a shared language ... rather than squeezing people's varied experiences into pre-existing categories’. Denscombe (2007, 92) claims that ‘the grounded theory approach fits neatly with the needs of researchers who are setting out to explore new territory’ and Urquhart (2013, 55) suggests that the grounded theory method is ‘good in areas where no previous theory exists’. These descriptions seemed to resonate with my proposed study.

A methodology based on a grounded theory approach has been used before with threshold concepts in what Tucker (2016, 94) claims was ‘an original approach’. However Tucker’s study was used to identify threshold concepts rather than to explore liminality. Subsequent to the data collection phase of my study Ng and de Guzman (2017) have used Straussian grounded theory to analyse transcribed interviews but this was reported too late to affect the methodological planning phase of my research.

Grounded theory resonated with my research approach in a number of ways. Firstly, some grounded theory researchers described grounded theory in terms that sound similar to liminal experiences: Urquhart (2013, 110) talked about capturing ‘the “lightbulb” moments we have about the data’ and Charmaz (2014, 116) talked about

an ‘interactive space’ in which preconceptions were challenged and uncertainty must be tolerated. Secondly, although it can be used with quantitative data Denscombe (2007, 92), Creswell (2003, 183) and Locke *et al.* (2010, 288) linked it principally with qualitative research. Thirdly, Taber (2000, 470) argues that grounded theory methodology builds on both the interpretive, idiographic type of educational research and the nomothetic, endeavouring to let nomothetic concepts emerge from the idiographic contexts; it ‘provides tools to achieve abstraction without completely sacrificing complexity’ as Kearney (2007, 128) expresses it. Fourthly, I sought to understand liminality from the perspective of the learner experiencing liminality and Denscombe (2007, 92) claims that grounded theory is particularly appropriate when studying ‘the participants’ points of view’. Finally, Locke *et al.* (2010, 192) state that grounded theory studies aim to go beyond description to ‘systematic explanation’. Denscombe (2007, 89) suggests that grounded theory is ‘dedicated to generating theories’ rather than testing them or just describing the data. My purpose was similarly to generate theory.

Grounded theory was ‘discovered’ by Barney Glaser and Anselm Strauss in 1967. Since then it has evolved to become a ‘family of methods’ (Bryant and Charmaz 2007a, 11) or ‘a constellation of methods’ (Charmaz 2014, 14); this evolution includes a significant split after 1992 into Glaserian and Straussian versions of grounded theory and the development of constructivist grounded theory by Charmaz (2014). It is therefore necessary to determine where to position this research within the grounded theory family.

The version of grounded theory popularised by Charmaz (for example, Charmaz 2014) reflects the constructivist turn seen in so many disciplines, such as, as we have seen, threshold concepts theory, physics and pedagogy. Charmaz (2014, 13) advocates constructivist grounded theory to avoid 'endorsing mid-century assumptions of an objective, external reality'. Urquhart (2013, 60) warns against believing that 'emergence' 'implies that there is some objectivist truth waiting to be discovered in the data.' Clark and Friese (2007, 369) seek to 'disarticulate' grounded theory from 'its remaining positivist roots'. Mills *et al.* (2006, 26) assert that 'constructivism is a research paradigm that denies the existence of an objective reality.' This suggests that my ontologically realist interpretation of threshold concept scholarship is incompatible with Charmazian grounded theory.

On the other hand, it resonates with classic grounded theory: Glaser and Strauss (1999, 4) say that 'theory is intimately linked to data'. The primacy of the 'raw data' (Strauss and Corbin 1998, 159) is one of the key features that distinguishes grounded theory from other interpretivist methodologies; for example Stern (2007, 119) says 'data are the building blocks'.

Even the constructivists accord primacy to data. Thus, Bryant and Charmaz (2007b, 32) state that 'theory emerges from the data'; Charmaz (1996, 33) talks about 'rich, detailed data'; and Urquhart (2013, 17) argues that theory is constructed from data. It appears that what the constructivist grounded theorists mean by data is rather different from an ontologically realist view: Charmaz (1996, 32) argues that 'the researcher actively constructs the data in concert with his or her participants.'

My study therefore seeks to select a position on what Mills *et al.* (2006, 26) call the 'methodological spiral' which is a hybrid between the classic grounded theory of Glaser and the constructivist grounded theory of Charmaz. This treats the processes of grounded theory as tools to capture glimpses of an underlying reality which, as Mills *et al.* (2006, 31) attest, constrains the interpretations placed on it by the researcher and the participant.

This hybrid methodology acknowledges the Charmazian rejection of the 'blank slate' doctrine because the 'researcher's own standpoints, historical locations, and relative privileges shape what they can see' (Bryant and Charmaz 2007b, 44). Nevertheless, it asserts that it is the responsibility of the researcher to endeavour to ensure that the data is as undistorted as possible. Thus, while the literature review has been more extensive that that normally accepted by classic grounded theory it serves as a way of making fundamental assumptions explicit to act as what Lietz and Zayas (2010, 193) call 'a statement of self disclosure'. It retains, as tools to reduce the distortions due to bias, the typically constructivist process of fragmenting the data before initial coding and then reassembling it. Another bias reduction technique common to most versions of grounded theory and retained here is the constant comparative method in which new piece of evidence is compared with the existing evidence and the existing categories (Holton 2007, 278; Taber 2000, 471; Urquhart 2013, 9; Glaser and Strauss 1999, 1967, 106).

This use of an ontologically realist but epistemologically constructivist hybrid of grounded theory was evident in the early sections of the investigation when, having transcribed three recordings, it was recognised that the disfluencies in speech might

provide extra information about the underlying thought processes of the respondent even though a layer of epistemological distortion might be introduced when they were interpreted.

3.5: Method

3.5.1: Design of data collection

There were a number of data collection techniques available to me including pre-test/ post-test; questionnaire; observation (participant or nonparticipant), individual interview, and focus group.

I had already decided against a pre-test/post-test design. The purpose of the investigation was to observe transformative learning as it happened, in order to study what Schwartzman (2010, 27) calls the ‘mechanism of learning’. The same consideration applied to using a questionnaire. Although a questionnaire might give me background information on my participants, the only way I could use it to probe liminality was to ask questions about experiences my participants might have had in the past. I was concerned about the distorting effects of both possible leading questions and memory, especially given a possible social desirability bias which might be maximised if they perceived a student expert relationship.

My review of the threshold concept literature has shown a clear if unarticulated assumption that liminality is experienced individually. I expected my investigation to

have an idiographic focus. This meant that the data collection should focus on individuals. For this reason I rejected using focus groups to collect data,

I had already decided I wanted to observe my participants while they experienced liminality. One way of doing this was to sit in classrooms observing the pupils as they learned; such a naturalistic setting would have been particularly appropriate to ethnography. In the early stages of my research this was what I did. However, I realised that there were two limitations of this approach. Firstly, not all learning involves liminality, at least in so far as to become observable. I did observe what I classified as liminal experiences in class but they were few and far between. I would have been unable to collect sufficient data using this approach.

Secondly, the liminal experiences I did observe were not really allowed in the culture of the classroom setting. When an individual learner becomes stuck the teacher can rarely spend more than a few seconds to explore the issues with that learner. The other learners who may or may not be facing liminality also require the teacher's attention. Only assertive individuals will interrupt the learning of the whole class whilst experiencing difficulties in understanding. Where individuals were clearly stuck I tried to speak to them on a one to one basis shortly afterwards, choosing a time when the class had been assigned individual work. This enabled me to explore liminality with the individual. But I found it difficult to go into depth. I return to this issue in section 7.2.6 when I consider stuckness and motivation.

I therefore decided to request volunteer participants to work with me on a one to one basis. I used a cognitive challenge to provoke liminality; apart from this starting point

the interview was unstructured. This choice of unstructured rather than structured interviews was in part prompted by the methodology. Denscombe (2007, 93) suggests that grounded theory has ‘a preference for unstructured interviews rather than structured ones’. Foster and Parker (1995, 167) suggest that unstructured interviews are favoured at least initially because structuring presupposes the categorisation which is supposed to ‘emerge’ from the data analysis.

3.5.2 Think aloud

I decided to use a think aloud technique to collect data. Land and Meyer (2010, 65) had suggested the use of ‘talk aloud’ methods; Green (1998, 5) distinguishes between talk aloud and think aloud by saying that think aloud but not talk aloud expects individuals to verbalise info that is not ‘already encoded in verbal form’.

My participants were told to ‘think aloud’ while they tried to solve the problem I was giving them; their utterances were recorded using a digital recorder. During the initial part of each interview I presented the participants with the stimuli; we moved to the next when I judged that they are solved the problem they were tackling, or if they were unable to solve it that they had no further thoughts to utter. During this part I restricted my input to prompting them to ‘please keep talking’ if they had paused a long time[3], ‘OK?’ if I thought they had finished, and to informing them that I was not going to give prompts if they seemed to be seeking assistance. However, during the latter part of the interviews I sometimes asked them to clarify what they had said or prompted them if they appeared irredeemably stuck. Finally during the feedback

[3] It is difficult to be precise about how long a ‘long time’ was. It depended on the individual and their typical pattern of pausing. The point is that I used my judgement to decide when to prompt or intervene.

stage the interview moved into more of a dialogue where I explored the ideas they had advanced. With some participants I also explored their feelings about their experience.

As determined by the purpose of the investigation, this was a concurrent think aloud technique. It is possible to have participants talk about an experience retrospectively but Green (1998, 6) points out that ‘retrieval is of course fallible’ and some information may be filtered or tidied up; Van Someren *et al.* (1994, 21) suggest it may be subject to ‘*post-hoc* rationalizing.’

There are potential problems to using what people say as data. We know that what participants say is not the same as what they are thinking (Green 1998, 4). Participants may misreport their thinking for a variety of reasons including deference and social desirability (Bernard and Ryan 2010, 33 - 37) which may have been a particular problem in the present study given that I was known to the participants as an ex-physics teacher; one of the participants reported that they expected that they would be told the ‘correct’ answer at the end of the interview. These considerations mean that as Dennett (1991, 78) says, ‘we can't be sure that the speech acts we observe express real beliefs about actual experiences; perhaps they express only apparent beliefs about nonexistent experiences.’ However, as Smith (1995, 10) notes, there is likely to be some sort of relationship between what someone says and what they think: ‘What a respondent says in an interview has some significance for him or her’.

One of my concerns about using a think aloud technique was that talking about one's thinking concurrently with doing the thinking might disrupt or distort the thinking in some way. This has been considered in the literature. Ericsson and Simon (1984, xiii - xiv) report that think aloud tasks do not change the sequence of thoughts and Van Someren *et al.* (1994, 32 - 33) found little evidence of disruption above the 'inevitable' distortion that comes with being studied, though they were aware that verbalization imposed extra pressures on memory. Although the solutions to the problem posed were not in the memory for most participants, they may have found it more difficult to access their memory of other areas of physics which they might have used to develop solutions. This might have increased the likelihood of stuckness.

Data was collected by recording interviews between myself and a participant. The first interviews relied on audio recording. The pattern for the first interviews was to give the participant a challenge in physics and then to ask the participant to think aloud whilst they attempted to solve it. At the start the participant was unprompted, except to be encouraged to vocalise during excessively long pauses. Later during the interview I would intervene, perhaps to check that the participant had finished their thought, perhaps to focus the participant more clearly on the challenge, perhaps to move the participant towards a solution. The aim was to let the participant struggle but not to let them give up. To this end the interviews were, apart from the initial stimuli, unstructured: the timing, the manner and the content of my interventions were highly variable, designed to explore what, at the time of the interview, I felt were interesting aspects of the liminality.

Where necessary, the participants were asked to clarify certain issues after the interviews had been transcribed. For example, f2 used the word ‘weird’ a number of times during one of her interviews and was subsequently asked to clarify what the word meant for her.

At the end of each interview, I explained to the participant solutions to the challenges posed. The participant was then asked whether they would take part in further interviews; all but one agreed. This suggested that whatever the participants experienced it was not sufficiently unpleasant to deter further participation. However, the second set of interviews was found to be inconsistent at provoking liminal experiences so the data was not used in the analysis.

3.5.3: The ‘dog on the bed’ challenge

The ‘dog on the bed’ challenge was chosen because it explores the understanding of Newton’s Third Law of Motion. Newton’s Laws are cited as examples of troublesome knowledge in Meyer and Land (2003). They are also regarded as potential drivers of conceptual change by, for example, Driver *et al.* (1985b, 195). Those studying the teaching of physics (for example, Poutot and Blandin 2015) also regard Newton’s Laws as problematic.

The participants were shown a series of captioned pictures (these appear in Appendix 1). The first picture showed a dog on a bed with a caption: ‘The dog has a weight of 100 N. What forces act on him when he lies on the bed?’. Once they had

considered this and responded they were shown a picture of a simple force diagram showing two forces: the weight of the dog (100 N) acting down and the reaction force from the bed of 100N acting vertically upwards. This usually agreed with their answer; it helped to standardise their thoughts.

They were then shown a second picture showing a (stuffed toy) meerkat lying on the bed with the caption: ‘The dog jumps off the bed and is replaced with a 5 N meerkat. What forces act on the meerkat?’. Following consideration of this stimulus most respondents quickly and correctly responded along the lines of the next picture which showed a force diagram where the downwards weight of the meerkat (5 N) is balanced by the 5N upward reaction force from the bed.

The respondents were then shown a final stimulus which showed the dog on the bed again with the caption ‘How does the bed adjust its reaction force so that it always balances the weight of the thing lying on it?’ This was the stimulus that was designed to put respondents into a state of liminality because most physics students are well aware that the forces must balance (as prescribed by Newton’s Third Law of Motion) but they are also aware that a bed is not conscious and that therefore it cannot ‘know’ how heavy the thing lying on it is in order to ‘choose’ the appropriate reaction force. There are a variety of correct answers to this apparent paradox. One might be that as the object (dog, meerkat, person etc) gets on the bed the bed springs are squashed; the heavier the object the more they squash; the more they are compressed the harder they push back.

Respondents who, with or without help, achieved some degree of solution were given another problem: how does the floor adjust its reaction force to match the weight of the person standing on it? The lack of obvious springs in the floor meant that most respondents re-entered the liminal experience; they were unable to generalise from the springs to, for example, the bonds between the atoms in the floor (which behave remarkably like springs).

Participants were asked to think aloud as their attempts to explain these challenges were recorded. I intervened where necessary.

3.5.4: Sampling

Like other interpretive methodologies, grounded theory emphasises the importance of context. This may mean that it is difficult to apply the results to other contexts (it has low external validity).

I wanted to investigate those learning physics shortly prior to university. This choice was because I had been involved for many years teaching physics at this level and I concluded that I had observed learners undergoing liminal experiences many times.

I chose to study learners aged between 16 and 18 studying the first year of A-level physics in a sixth form college. The choice of college meant that my participants were from a wide variety of backgrounds (rather than, for example, all attending a fee-paying school). In addition, the learners were all studying with the same teacher.

None of them had encountered this teacher prior to the start of the academic year. I observed a number of lessons prior to the interviews to gather contextual information about the background understanding of the learners prior to the interviews. Thus I ensured that all participants had been taught Newton's Third Law prior to taking part in the interview.

Grounded theory methodology uses a sampling strategy called theoretical sampling; Denscombe (2007, 95) makes the point that this is a type of purposive sampling. Theoretical sampling, in which the emerging theory is used to control the data collection (Glaser 1978, 6; Charmaz 1996, 31), requires that at least one category has been developed (Charmaz 2014; 199, 204) but can then be started. New participants, or new contexts, or new questions, etc are selected (Noerager Stern 2007, 116; Charmaz 2014, 192). Bernard and Ryan (2010, 369) characterise theoretical sampling as following suggestions in the evidence as theories develop. This creates a potential bias in that one's early half-formed theories guide the collection of later evidence. However, Morse (2007, 231 - 234) defends this technique as a way of gaining adequate data about less common categories without being swamped by data in the more common categories; however, she acknowledges that this creates an inherent bias.

Having defined the context I called for volunteers. Ten from a potential 24 of the first cohort volunteered; most of whom were used in the first round of interviews (for some there was a difficulty in arranging the interviews; one withdrew from the physics course before his interview was conducted). Theoretical sampling implies that the analysis of the initial data guides subsequent data collection. This was done

in the second round of interviews which were conducted on the parallel classes twelve months later.

Although random sampling techniques might be the most effective way to control bias, Krippendorff (2013, 115) makes the point that probability sampling techniques only make sense when each sampling unit contains an equal amount of information which was unlikely in this investigation. Given that, in theory if not in practice, grounded theory data collection starts without preconceptions, we cannot sample randomly because we do not have *a priori* variables on which to randomise. Morse (2007, 231) recommends using convenience sampling with articulate, expert informants although this in itself begs the question of how we know who the experts are if we have no preconceived ideas.

Hood (2007, 153) suggests that the 'General Inductive Qualitative Method' uses purposeful sampling and that 'data collection stops when additional cases no longer add new information'. Bernard and Ryan (2010, 360 - 361) suggest that this will be after between 10 to 20 informants depending upon their expertise (fewer informants are needed if they are more knowledgeable); I interviewed 19 respondents over two tranches, seven in the first and twelve in the second. The grounded theory method continues collecting data until 'theoretical saturation' is reached; this is when you hear 'nothing new' (Stern 2007, 117); when 'no additional data are being found' (Glaser and Strauss 1999, 1967, 61); when 'fresh data no longer sparks new theoretical insights' (Charmaz 2014, 213). Determining this point is a particular concern in the design of this study because although the context of pre-university physics learning is well-bounded the concept of liminality is not well-bounded. This

means that it may be difficult to decide when no further information will be forthcoming; although my second tranche of respondents delivered few new coding categories how could I decide whether a third tranche might not be needed? However, this was always designed to be an exploratory study. This is therefore 'semi-permeable' theoretical saturation in which the codes and categories developed are considered robust, but the possibility is left open that there may be codes or categories undiscovered. For example, the strategies that have been listed are well-evidenced but there is no claim that other respondents might not use other strategies.

There are several potential sources of bias due to sampling which I acknowledged as part of my design.

- Because I was studying physics there were significantly more male respondents than females (16 compared to 3). This reflected the proportions within the groups I studied.
- My use of volunteers meant that my respondents were likely to be more self-confident as learners. This agreed with my observations of how my participants behaved during the informal observations of their lessons that I conducted in the weeks immediately prior to the interviews. This might have had a particular effect when I analysed the affective nature of the responses such as the fact that I found no negative motivational issues with this cohort.

3.5.5: Microanalysis

Since I was using the grounded theory method, the data collection and the data analysis overlapped (Urquhart 2013, 8). Although there was initially a short phase in which data was collected alone, after a few interviews the process of transcribing and analysing the data began.

The first phase of data analysis involves breaking up the data into conceptual components (Glaser 1978, 55; Bernard and Ryan 2010, 271; Strauss and Corbin 1998, 102; Charmaz 2014, 113). Starting with a single transcript (Smith 1995, 19), the verbal protocols were microanalysed (Strauss and Corbin 1998, 58), that is, the transcripts were segmented into phrases, clauses or sentences, 'each segment corresponding to a chunk of behaviour such as a statement or a phrase' (Green 1998, 19). Most of these segments lasted a few seconds. An example of a microanalysis is shown below (Table 1).

After three transcripts had been microanalysed, their characteristics were examined, at first individually and later in comparison with one another. This examination was written up in 'primary memos'. These were 'partial, preliminary, and provisional' (Charmaz 2014, 181); they were treated as transient so that the memo for one participant's transcript was revisited and added to where comparison with another microanalysis suggested this should be necessary. By comparing the three transcripts I was able to design a provisional template for characteristics to look for; this template was also provisional and I added to it as I studied more microanalyses.

TIME	TRANSCRIPT	COMMENT
2m39.0s	But it's a lot quicker.	
2m40.7s	That's my answer	Laughs
2m42.3s	OK and how does the bed adjust ... from dog to meerkat?	Experimenter intervention
2m48.0s		Pause
2m50.6s	Don't know	
2m50.9s		Pause

Table 1: An example of a microanalysis

The microanalyses were then coded, line by line or word by word (Charmaz 2014, 124) by myself (as recommended by Glaser 1978, 58). The purpose of the coding was to 'select, separate and sort data' (Charmaz 2014, 111). Some segments were coded with multiple codes. In grounded theory, the ideal is that the codes should 'emerge from data' (Hood 2007, 154). *In vivo* codes (Kelle 2007, 199) were used where appropriate to reduce bias caused by *a priori* theories although the initial

decision to use only *in vivo* codes was soon found to be impractical because respondents expressed very similar ideas in different ways and because some codes were needed to describe what a respondent was doing rather than what they were saying (for example ‘explaining’). After coding the first three transcripts, each new coding was compared with the previous codes used. When a new code emerged the already coded transcripts were revisited to see whether the new codes were applicable to them. This constant comparison method (Holton 2007, 278; Taber 2000, 471; Kelle 2007, 194) was also used to modify and merge codes where appropriate. Some codes were differentiated: for example it was recognised that ‘yes’ tended to mean something different from ‘yeah’, that repetitions could be associated either with the beginning or the end of liminality, and that there was evidence for two forms of stuckness.

In microanalysis the transcript was fragmented into chunks and timings were added. The timings were approximate: by retiming a small sample it was established that the timings were almost always repeatable within 0.2s; this was regarded as a reasonable estimate of the accuracy of the timings given. The third column was used for comments (for example, ‘laughs’, ‘whispers’ etc) and contextual information.

3.5.6: Pauses cause the method to be revised

In accordance with standard grounded theory procedure there was no pilot study (although Nunes *et al.* 2010 have suggested that the use of a pilot study within a grounded theory enquiry offered ‘a more articulated view on the internal structure of

wider phenomena'). Instead, data analysis was reviewed after the first three interviews. This led to a significant modification of the method.

At the outset I had resolved to limit my coding to the verbal responses of the participants, even to the extent of using only *in vivo* codes in the substantive coding. However, it became clear during the transcription of the first interview that paralinguistic features of the utterances were important. Such features as pauses, whispering, repetitions and verbal fillers such as 'yeah' provided an alternative set of data which was based on **how** the participant verbalised thoughts rather than **what** they said. This offered another way of interpreting the data allowing the possibility of a limited form of triangulation. It also provided a relatively objective way of viewing the data so reducing the effect of experimenter bias.

This had not been expected. The examples of a political speech and an interview given by Urquhart (2013) in her practical guide to grounded theory and an interview coded by Charmaz (2014, 145) show no examples of non-lexical items such as hesitations. This may be an artefact of the transcribing process. On the other hand Charmaz (1996, 33) recommends that data should include context, verbal and non-verbal cues. Pauses, as well as repetitions, changes in the speed of talking and changes in voice are among the features of think aloud listed by Bernard and Ryan (2010, 56 - 63). My transcripts were full of hesitations and pauses, some filled, and repetitions and other lexical and non-lexical items. This was a potential source of evidence that I was unwilling to ignore.

My earliest transcripts suggested that pauses were associated with statements such as ‘I don’t know’ and that cognitive challenges tended to provoke long pauses.

On the other hand, it was recognised that pauses have a variety of causes. For example, some pauses represent time taken to breathe. However, Green (1998, 17) found that ‘individuals often fall silent when encountering task difficulties’. A literature search revealed little data on the length of a typical pause (see below) so I decided that pauses shorter than 0.2s would be represented by punctuation (for example, commas, semi-colons and periods). This was because my timing procedures were accurate to within about 0.2s. Pauses longer than 0.2s up to 1s would be represented using ellipsis. Pauses longer than 1s would be timed and recorded in the transcripts.

This introduced a quantitative element into what had hitherto been a purely qualitative study. However, a nomothetic quantitative analysis of the length of pause was considered impractical, especially given that individuals had very different typical pause lengths. However, knowing the length of pauses proved useful when interpreting what might be happening during the pause on an individual basis.

Gleaning extra data from, for example, pause length was useful because otherwise, as Van Someren *et al.* (1994, 33) warns, silence represents incomplete data. One assumes people are doing and thinking while talking but one cannot assume that they have stopped doing and thinking when they are silent.

It is not always clear exactly how long a pause takes. For example, most participants followed the instruction to read the stimuli aloud but many participants sometimes forgot to do this so it was not possible to tell where reading stopped and pausing started. Similarly, when participants had finished a statement there might be a pause which I terminated after deciding that the respondent was not pausing for thought but had finished and was waiting silently for the next stimulus.

Another example of a pause coding problem came from the very first transcript. After confessing ‘To be honest I don’t really understand ... Newton’s Third Law’, m1 then proceeded to apply it successfully to the example of a person standing on a floor. He then got stuck. After a 2.7s pause he said ‘so’ and then paused again for 2.1s. He then said ‘yeah’ and paused for 2.4s. Excitedly he then said: ‘So ok ok ok so that would be’ and paused a fourth time for 2.3s before beginning a hesitant explanation of what was happening. Were these four separate pauses? Was there a long pause of 7.8s containing the lexical fillers ‘So’ and ‘Yeah’ followed by the revelatory ‘So ok ok ok ...’? Or was there just a single long pause of 12.1s in which the lexical fillers included ‘So yeah ok ok ok so that would be’? (NB Where pauses have been aggregated the time taken to utter the lexical fillers has been added in.) This evidence exemplifies why a simple quantitative analysis is inadequate. The actual length of the pauses is less important than the fact of them. A sensitive reading of the transcript segment suggests that the pauses indicate that the respondent is in deep thought. The ‘yeah’ suggests that he has thought of something that might seem to solve the problem. The excited ‘So ok ok ok so that would be’ indicates that he has thought of a solution; there is a further pause while he either reviews this solution to check that it fits or perhaps seeks words in which he can articulate the

solution he has perceived. In summary this is key evidence of a liminal experience for which the pauses, whether four or two or one, are important indicators.

A second example comes from m2. When he started trying to explain how the bed adjusted its reaction force to match the weight of the thing lying on it he initially denied it: ‘I don’t think the bed ...literally adjusts its reaction force, I think ...’ There was then a 0.8s pause (normally coded as a hesitation; timed for the purpose of investigating what was happening in this case) before he said ‘when’ followed by a 3.8s pause. ‘When’ is not normally a lexical marker and does not seem to have been used as such by m2. Instead it seems likely that it was a fragment of the thought he was having silently inside his head. But should this be transcribed this two pauses broken by an articulated thought, however fragmentary, or as a single pause filled with a word?

Another example is that of m3. After the experimenter has asked ‘*Have you done any work with springs?’* m3 replies ‘Err ... yeh ...It ... err’ and it seems sensible to record this as a filled pause of 5.4s. He then states: ‘That was with the ... stress and strain’ and pauses again, filling this pause with ‘Umm ... Oh God ... That was ... err’. The second ‘That was’ might be evidence of the beginning of a thought but since this last utterance has a duration of 8.5s it seems more sensible to code it as a pause.

A review of the literature to ascertain how long a silent pause typically lasts in normal spontaneous speech produced little guidance. Two reasons were suggested for this. The first referred to the difficulties of measuring pause length mentioned above. The second possibility was that individuals have very different typicalities in speech,

perhaps because the conditions in which spontaneous speech is produced vary so widely that it makes little sense to talk of ‘normal’. These difficulties have led to some researchers ignoring silent pauses. For example, Bortfeld *et al.* (2001, 141) reported that they ‘avoided coding silent pauses since their identification is extremely subjective’. However, it was decided in this experiment to record the pauses because they appeared so important. As Wood and Kroger (2000, 62) point out: ‘silence is not just an absence; rather, it is an absence that is unexpected and inappropriate’.

Some guiding literature was discovered. Goldman-Eisler (1972, 106) measured pauses in spontaneous speech; her participants were academics who might be expected to be more fluent and articulate than the typical school student. She found that over 90 per cent of pauses between words within clauses were shorter than 0.25s; that the length of a pause between clauses within a sentence depended to a substantial degree on the nature of the clauses but that ‘durations beyond 0.75 sec are difficult to sustain in transitions between clauses’; and that although half of sentences were separated by pauses of more than 1s only 15 per cent of sentences were separated by pauses of longer than 2s. The pauses in the example transcripts in Edwards and Westgate (1994, 66 - 67) vary from 0.3s to 3.4s, most of them lasting 1s or shorter. De Jong and Bosker (2013) measured silent pauses of people speaking a second language and found about a quarter of the pauses were no longer than 250ms and very few indeed were longer than 3s. A study of hesitations in Estonian revealed that fewer than 10 per cent lasted longer than 500ms.
Some researchers create pauses in utterances to observe the effects of hesitant speech on listener comprehension. Miller and Grosjean 1981 varied the lengths of

pauses in the utterances they used to measure comprehension but none of their pauses exceeded 1s in length. Boomer and Dittmann 1962 found that hesitation pauses had a different function from pauses which marked sentence structure but their longest pause was 0.5s.

Many of the pauses in this study seem to be longer than the pauses reported elsewhere in the literature. This may be because the task was challenging; Bortfeld *et al.* (2001, 123) found that when one participant was giving oral instructions to another the disfluency rate increased as the difficulty of the task increased (although the distribution profile of filled pauses was different from that of other disfluencies) and Edwards and Westgate (1994, 64) state that 'pauses are likely to be more frequent in ... exploratory talk'. Alternatively, either the task or perhaps the think aloud conditions may have generated anxiety; Christenfeld and Creager (1996, 454) report that 'silent pauses, sentence restarts, and repetitions ... have been shown to reliably increase in anxiety studies.'

On the basis of the literature reviewed above, and taking into consideration the distribution of pause lengths found in the first seven transcripts (see section 4.2.1), it was decided that pauses of longer than 1s would be timed and recorded.

3.5.7: Other speech disfluencies

Other paralinguistic features were also observed. Maclay and Osgood (1959, 24) use the term 'hesitation' to mean repetitions, filled pauses, unfilled pauses and

‘incomplete or self-interrupted utterances’. Other researchers into speech have different ways of classifying speech disfluencies. The early transcripts suggested that repetitions and laughter were associated with potential solutions to the problem suggesting that they offered markers for exiting liminality and revealed that certain words, for example ‘yeah’ might mark other characteristics of liminality. Whispering and muttering was also recorded. This was in line with the suggestion of Bernard and Ryan (2010, 56 - 63) that analysis of such features can contribute to understanding the thoughts behind the transcripts

A repetition is classified as a sign of disfluency by Christenfeld and Creager (1996, 454) and Maclay and Osgood (1959, 24). Kasl and Mah (1965) suggested that speech disfluencies increase when subjects grow more anxious and, since it was presumed that liminality might provoke anxiety, it was expected that speech disfluencies such as repetitions might be a feature of these transcripts, as had been discovered. On the other hand, Clark and Wasow (1998, 225) state that ‘in repeats, speakers make what outsiders would call premature commitments: they produce a word and then immediately suspend their speech.’ This suggested that repetitions might mark moments when respondents in liminality might prematurely believe they had achieved a transformation in learning. Both descriptions of repetitions suggested that they might mark characteristics of liminality. Repetitions were therefore coded and the context in which they occurred was scrutinised.

Lalljee and Cook (1975, 303) found that some ‘units of ritualized speech’ such as ‘well’ and ‘I mean’ increased in frequency when respondents were more anxious. Since the literature review suggested that some learners experience anxiety during

liminality it was expected that there would be evidence of such units, which I termed ‘lexical fillers’, when respondents were experiencing liminality.

Another suggestion was that gesture might reveal things that transcripts could not. Having amended my initial ethics submission and having obtained individual permissions each time, I videoed the interviews for a small number of participants. The microanalysed transcripts for these participants recorded actions such as hand and eye movements. Again this data was compared with the verbal data and used to contextualise it. In the end, however, there was insufficient video data to discern clear patterns and no formal use was made of this data.

Following Clark and Fox Tree (2002) non-lexical fillers were mostly classified as err and umm although occasional variants were recorded where it was felt that they might convey more meaning than simple pause fillers. For example, f2 uses ‘ooh’ which might indicate surprise and m5 ‘aah’ which possibly suggests enlightenment. However, there were very few of these so no systematic analysis was undertaken.

Clark and Wasow (1998, 223) state that ‘speakers use uh and um mainly when they anticipate longish delays’; these non-lexical fillers are therefore used to tell the listener to expect a longish pause. The non-lexical fillers were therefore categorised as pauses and the analysis and timings done of long pauses include the non-lexical fillers.

3.5.8: Constant comparison and theory emergence

Constant comparison also helped judge the approach of theoretical saturation since few new codes emerged on the second tranche of respondents.

Holton (2007, 272) and Strauss and Corbin (1998, 66) recommend moving from descriptive to conceptual codes as soon as possible. This was facilitated by writing memos in parallel with the coding process. The memos recorded speculative conjectures and began to reintegrate the data by initiating the grouping of codes into categories. The categories were built using the method of constant comparison; considering how codes were the same and how they were different (Strauss and Corbin 1998, 66); this helped to establish the boundaries of the categories (Glaser and Strauss 1999, 1967, 24) although it was recognised that there were alternative ways to group the data (Strauss and Corbin 1998, 104) so these category boundaries were necessarily fuzzy and provisional (Dey 2007, 169 - 170; Charmaz 2014, 181).

Gopnik and Wellman (1994, 260) point out that categorizing evidence by itself can only result in ‘empirical generalization’. Developing a theory requires developing ‘theoretical constructs’ and ‘causal explanations’. Therefore the research progressed towards discovering the relationships between categories (Strauss and Corbin 1998, 102 - 103) and seeking hypotheses that account for these relationships (Holton 2007, 265; Glaser 1978). The memos were used to reflect on the data (Urquhart 2007, 352) and to begin to distill data into theory, creating narrative (Bex Lempert 2007, 245). Earlier memos were sometimes used as the data for later memos (Bex Lempert 2007, 258). The literature review was restarted because some of the

emergent ideas such as promisingness and reflective self-dialogue had not been expected and therefore had not been covered in the original literature review.

3.5.9: Reducing the opportunity for bias

The positioning of the methodology of this study between classic Glaserian and Charmazian constructivist grounded theory avoids both the postmodern perspective of multiple truths, that the emergent analysis is just 'one view among many' as Charmaz (2014, 132) puts it and the Glaserian disapproval of a researcher with doubts; Glaser and Strauss (1999, 224 - 233) suggest that such researchers are 'tempted toward a compulsive scientism' and that their very endeavours to cross-check their results suggest that they are 'running away' from their conclusions. I acknowledge with Denscombe (2007, 101) that 'without necessarily intending to do so, researchers can ... end up being selective about what they 'see' ... managing to corroborate their theory by a process of selective perception'; I accept the argument of Ausubel *et al.* (1978, p 92) that 'concepts, once acquired, influence ... the perceptual categorization of experience' and I concur with Charmaz (2014, 26) when she points out 'how you collect the data affects which phenomena you will see'.

There are error-reducing procedures in much of qualitative research that grounded theorists do not usually do. For example, in other methods of doing qualitative research all transcripts are coded by two or more coders. Their codes are then compared (a) to reduce discrepancies and (b) to provide an estimate of inter-rater reliability. However Glaser (1978, 58) stated that in order for the analyst to gain an intimate depth of understanding of the data 'the analyst must do his own coding'. Furthermore, the constructivist perspective on grounded theory points out that each

analyst will interact individually with the data (Lietz and Zayas 2010, 193) which makes the interpretation of inter-rater reliability problematic. For these reasons the present research was done using only myself to code. This inevitably removed the possibility of reducing bias by using the perspective from a second pair of eyes with a different potential bias.

Although Lietz and Zayas 2010, 197) suggest that 'negative case analysis is a strategy ... commonly employed in a grounded theory approach', other grounded theorists, for example Charmaz (2014, 198), warn against seeking negative cases. If discrepant data does arise it is often treated as extending the range of the theoretical categories, rather than casting any doubt on them (Taber 2000, 475; Strauss and Corbin 1998, 160). The process of starting theorising after only a small amount of data has been collected means that data collected early may have a greater importance than data collected later; the final conclusions might be different had the evidence been gathered in a different order.

There were therefore ways in which bias might enter the study. On the other hand, there were several techniques used in this study to reduce bias. The transcripts were fragmented into microanalyses to help the investigation to 'refrain from imputing your motives, fears or unresolved personal issues to your respondents' (Charmaz 1996, 37) and to 'avoid taking one stand or stance toward the data' and to enable the researcher 'to examine what assumptions about data they are taking for granted' (Strauss and Corbin 1998, 58 - 68). Many of the codes used, such as pauses and repetitions, were quasi-objective which reduced the potential for experimenter bias. The method of constant comparison was used as a built-in and iterative process of

cross-checking, as recommended by Taber (2000, 471), Kelle (2007, 194), Holton (2007, 278), Urquhart (2013, 9), and Charmaz (2014, 132). Finally, as recommended by Taber (2000, 470 - 471), data was observed from multiple viewpoints, for example by analysing co-occurrences of pauses with phrases meaning ‘I don’t know’.

The constructivist perspective is that a researcher will tend to notice what their expectations have primed them to see. This is therefore a potent source of bias. Thus, when I identified two sorts of stuckness it seemed original but a re-examination of the work of Savin-Baden (2008, 81) and Burbules (2000) showed that the idea was present in literature already reviewed which might have preconditioned my expectations. On the other hand the emergence of the concepts of reflective self-dialogue and of promisingness were not presaged by literature I had previously encountered and demanded a second literature review as part of the discussion. That novel concepts were able to emerge suggests that researcher bias while undoubtedly present did not predetermine the outcome of this study.

For these reasons it is argued that the realist-constructivist hybrid of grounded theory used in this study enabled the results to be analysed in a robust and trustworthy way such that justified conclusions could be drawn.

3.5.10 Researcher’s positionality

Although I deliberately chose to conduct the empirical research in a context where I was not previously known as a teacher, I was introduced to the students (some of whom were to become my respondents) as an ex-teacher of Physics. Furthermore, I

acted as a voluntary teaching assistant in their Physics classes for some weeks prior to conducting the interviews.

This was not full scale participant observation as described by Punch (2009, 157 – 158). Rather my researcher position was closest to that described by Newby (2010, 367 – 368) as ‘Inactive and Known’. That is, I was not actively participating in the same activity as my respondents (I was not a fellow learner) but I was known to be involved in that activity. To use a metaphor, I was positioned half-way through the door. The aim was to achieve what Angrosino (2012, 166) describes as ‘to become enough of a member to gain an insider’s perspective on what is going on … this subjective perspective ideally complements, rather than replacers, the outsider’s overview.’

This positionality reflected the methodological considerations. For example, in section 3.3.2 I decided that, in contrast to the principally etic nature of most Threshold Concept research, I sought an emic perspective, trying to understand liminality from the perspective of the learner travelling through it. However, this understanding was based on observations of the learner’s think aloud data, an essentially etic point of view. Furthermore, I recognised in section 3.4.2 that my inability to pose as a participant made an ethnographic methodology inappropriate. At the same time my semi-insider status might have influenced the responses of my participants as noted in 3.5.2. This half-in, half-out positionality creates “potential role-conflicts” as discussed by Humphrey (2012, 573) although the ethical dilemmas on which she focusses are essentially based on breaches of confidentiality which were not relevant to this study and, indeed, the slightly less than 50% volunteer rate

of this study suggests less need for ethical concern than the 100% volunteer rate she reports.

Mercer (2007, 3 – 4) rejects the insider – outsider dichotomy in favour of a multi-dimensional continuum with a permeable and unstable boundary and notes both advantages and disadvantages to insiderness. For example, the researcher's identity which has stabilities such as gender, evolving stabilities such as age, and much less stable dimensions such as power relationships. But the degree to which a researcher is an insider is also modified by the way in which the researcher is perceived by the respondent and in a study with multiple respondents this will add a further dimension of fluidity to the degree of insiderness. The approach of the present study in which an emic interpretation is attempted of etic data is an attempt to follow the lead of Dwyer and Buckle (2009, 62) to 'embrace and explore the complexity and richness of these space between entrenched perspectives'.

It must therefore be acknowledged that researcher positionality might affect the data and its interpretation in complex ways. For example, it might affect the way that the participants responded during the interviews as discussed in more detail in section 6.7.6. It might also affect how the data was interpreted. The Grounded Theory methodology is particularly appropriate where there are considerations of constructing theory from qualitative data and this consideration of researcher positionality reinforces the placing of my research as a hybrid of classic Glaserian Grounded Theory and Charmazian constructivist Grounded Theory.

Chapter 4: Results: Indicators of liminality

When the empirical phase of this study began it was immediately recognised that non-verbal features of the responses contained information to supplement what the respondent actually said. Coding of what was said was therefore suspended. Instead, the first seven transcripts were inspected to determine where the respondent appeared to be experiencing liminality, for example where they said ‘I don’t know’ or words to that effect. A segment which showed liminality was extracted from each transcript. These segments were then scrutinised to elicit non-verbal features. The features elicited were pauses, laughter, whispering and muttering, repetitions, lexical fillers such as ‘yeah’ and ‘so’, and vacillation.

The full transcripts were then scrutinised for these characteristics. The aim was to see whether they might act as indicators or markers of aspects of liminality. Therefore the extent to which they co-occurred with other evidence of liminality (such as ‘I don’t know’) was assessed. It was established that pausing, laughing, whispering and muttering, repetition, and the lexical filler ‘yeah’ were trustworthy markers of liminality.

Coding then began using these markers to focus attention on categories of liminal behaviours. The categories were first described; these were refined using the constant comparative method.

In the following work a period of silence of longer than 0.2 seconds but less than one second is marked as '...' and a 'pause' of longer than one second is marked as, for example, '... [2.4s] ...' in which the length of the pause is given inside the square brackets.

4.1: Eliciting possible indicators of liminality from extracts from transcripts

It was noted from the first three transcribed interviews that certain disfluencies seemed to characterise moments of uncertainty and puzzlement. Hence it was decided to elicit characteristics of the transcripts of the first seven respondents that co-occurred with moments when the respondents seemed to be experiencing liminality. An extract from each respondent was chosen; the criterion for choosing the extract was that it had to include stuckness which the literature review had suggested was a key characteristic of liminality. Stuckness was assumed to occur when the respondent used an expression such as 'I don't know' or 'I have no idea'.

However, it was quickly recognised that the use of these phrases did not always suggest stuckness. For example, m5 seems to use the phrase in different ways:

- 'there's always going to be an equal and opposite force dependent on what's on it ... that's Newton's First Law, is it the First Law? might be third? is it first? ... I don't know'
- 'so say if you put, like ... I don't know a thousand tonnes on it or something'
- 'I don't know ... [11.7s] ...Right, so ... [2.5s] ... to balance it out ... it'll push back on the object with the same force that it the object's pushing down on it ... so on the bed'

In the first example he uses ‘I don’t know’ to suggest that he is uncertain of his facts; in the second that he is making an inexact estimate. It is only the third example that suggests he is (temporarily) stuck.

F2 also uses ‘I don’t know’ in different ways:

- ‘I don’t know that atoms behave quite like springs’
- ‘I don’t know you just take ... you don’t really think about ... your hands being like magnets’
- [7.5s] ... ‘I don’t know what else ... to do’ ... [7.4s]

In the first two extracts f2 is using ‘I don’t know’ to indicate that she is making a hypothesis which she is uncertain about; the phrase expresses doubt. In the third example she is indicating that she is stuck.

Other examples when respondents used ‘I don’t know’ included:

- M2 expresses imperfect assurance when he describes atoms as ‘squished together again like .... I don’t know what’
- M8 uses ‘I don’t know’ to express factual ignorance: ‘I don’t know what it is about the desk that stops my hand going through’.
- M8 also uses ‘I don’t know’ to speculate, initiating a white queen strategy of imagining the impossible: ‘let, let’s treat the bed like, I don’t know, a fluid’ at which point he laughs.
- M3, seeking a mechanism for how the floor pushes back, uses ‘I don’t know’ to suggest uncertainty. ‘Err ... there’s ... the carpet’s pushing ... but err ... [4.3s] ... I don’t know that.’

The extracts below were therefore selected after alternate interpretations had been dismissed.

4.1.1: Extract one (m1)

This follows my asking '*How does the bed adjust its reaction force?'*

'... [6.4s] ... The reaction force changes ... [1.5s] ... due to Newton's Third Law ... so .... So ... The weight of the ... dog down or the thing down ... err ... [1.5s] ... And then then ok so the bed is pushing back on whatever is on it ... so when some the thing on it changes its ... mass or weight ... then the reaction force on it is going to change as well ... [1.2s] ... So ... the bed [inaudible] is just whatever's on it, on top of it, it reacts to that ... [3.3s] ... I don't know ... I don't know ... I'm thinking that it's whatever's pushing down on the bed is gonna push back so that's ... how it adjusts it's not like it is physically doing it ... because it is ... not alive like the ... weight pushing down ... so it's pushing back ... with the same magnitude ... [3.7s] ...'

The phrase 'I don't know' expresses the uncertainty which is supposed to be a characteristic of liminality; this provides justification for assuming that this extract shows the respondent experiencing liminality.

During this extract the respondent gives an answer 'due to Newton's Third Law' but he seems to recognise that this does not answer the 'how' in the question because he later says 'how it adjusts it's not like it is physically doing it ... because it is ... not alive'.

The extract contains many hesitations and longer pauses. It contains repetitions both of words (‘so ... So ...’, ‘then then’) and phrases (‘I don’t know ... I don’t know’). It contains non-lexical fillers (‘err’) and lexical fillers (‘so’, ‘then’, ‘ok so’). There are moments when the structure of the phrases is fractured (‘so when some the thing on it’).

4.1.2: Extract 2 (f2):

‘... [2.1s] ... I have no idea ... [14.7s] ... I don’t know. It’s just the question ... is just weird ... [1.4s] ... Like I don’t think of the, like ... thing is adjusting ... [1.4s] ... to ... a weight but it does ... I don’t know how ... [1.6s] ... I’m just trying to think of everything that I know ... concerning forces’.

The use of ‘I don’t know’ (and ‘I have no idea’ and ‘I don’t know how’) again evidence the uncertainty that suggests liminality. This respondent is trying to explain what the problem is and to outline a strategy ‘think of everything that I know’ that might help.

Again, there is evidence of hesitation and pauses (one lasting 14.7s!) and a lexical filler (‘like’) which is repeated.

4.1.3: Extract 3 (m2):

In this extract, taken from relatively late on in the problem solving process, m2 is trying to develop the idea that the reason that a surface can provide a reaction force is that the object resting on the surface displaces the electrons in the surface.

‘They’re ... no longer stable they’re being pushed in and they’re not, no longer in their ... regular position ... ... um ... [3.0s] ... so then ... [1.5s] ... they push back ... [3.3s] ... [almost whispering] they get squished, they push back ... [1.6s] ... [normal voice; laughing] so I’ve no idea what I’m talking about ... err ... [1.4s] ... they push back with ... [2.4s] ... the same amount of force that ... [2.4s] ... is put down on them to keep ... their position ... [2.3s] ... No idea ... [8.8s] ...’

Twice m2 confesses he has ‘no idea’ and eventually he becomes silent; the final pause being broken by myself. The uncertainty and the stuckness both suggest that m2 is experiencing liminality.

Other characteristics of the transcript again include pauses and hesitation and a non-lexical filler (‘err’). Again, there is repetition although the repeated phrase (‘they push back’ repeated twice) is separated. One phrase is spoken very quietly; another is accompanied by laughter.

4.1.4: Extract 4 (m3):

This follows me asking: *‘So how does the surface, whatever the surface is, adjust its reaction force so that it does always balance... uh ...the weight of the thing lying on it?’*

‘...[2.4s] ... I don’t know [sounding amused, perhaps a little pleading] ... umm ... [8.6s] ... umm ... Well there’s no way for it to know OK but ... [3.5s] ... [almost whispering] I don’t know any... [3.1s] ... explain ... umm ... [7.1s] ...’

Twice m3 says he does not know.

Other characteristics of this extract include, again, the pauses and the hesitations, the non-lexical fillers, again there is whispering and there is a hint of amusement.

4.1.5: Extract 5 (m4):

In this extract m4 is trying to apply his understanding of how a spring-filled mattress can balance the weight of a dog lying on it to people standing on a floor.

‘But I don’t know how ... it’s hard to explain with ... [1.3s] ... the ground ... it’s just not ... it’s ... well everything has a ... plastic range ... but ... it doesn’t have ... [1.5s] ... But it’s not as much ... [1.6s] ... as ... the spring because the floor’s got a really small, because it’s brittle, hard, it will break easier.’

This is more fluent but there are still pauses and hesitations. He seems to stop one train of thought at the 1.5s pause and have difficulty starting a new one.

4.1.6: Extract 6 (m5):

This is another extract from relatively late in the transcript. I have previously asked m5 to apply his understanding of how a spring-filled mattress works to a person pushing down on a desktop.

‘... [14.0s] ... I’m not sure ... [1.3s] ... Well, it’s not like the desk’s getting compressed because you’re leaning on it ... [1.9s] ... unless to some extent it is which I don’t think it is ... unless the desk is gonna ... ... it’s gonna push back ... [1.8s] ... bounce back ...

it will still push back ... but it wouldn't bounce back like a spring would ... [1.2] ... because that's not how it's designed to act, it's designed ... [1.5s] ... compress, to push up ... so ... [3.1s] ... I don't know'

'I'm not sure' and 'I don't know' start and end this extract, suggesting uncertainty and stuckness. M5 seems to be in liminality. Other signs include the pausing and hesitation, the repetition (for example, of 'gonna' and 'it's designed') and lexical fillers such as 'well' and 'so'. The vacillating between 'push back' and 'bounce back' is an interesting feature given that threshold concept theory suggests that liminality may involve oscillation.

4.1.7: Extract 7 (m6):

M6 has also been grappling with transferring his new understanding of a spring-filled mattress to a weight on a floor. He was specifically asked: '*Are there anything like springs in the floor?'*

M6 answers: '... [2.6s] ... Possibly ... [1.8s] ... Well, there's a carpet ... but that's not really floor ... ummm ... [8.8s] ... [Laughs] ... err ... [2.0s] ... It'll be in the floor ... [2.2s] ... Like ... or something under the floor, inside ... [in a whisper] the floor ... [4.0s] ... [normal voice] ... Umm, I don't know ... [3.5s] ...'

As well as the pauses and hesitations and the lexical and non-lexical fillers there is evidence of laughter and whispering.

4.1.8: Summary of findings from the extracts

These extracts provided a list of possible indicators of liminality:

- Pauses and hesitations (including non-lexical fillers)
- Laughing
- Whispering or muttering or substantial reductions in volume
- Repetitions of both words and phrases
- Lexical fillers
- Vacillation

4.2: Co-occurrence of indicators of liminality with ‘I don’t know’ statements

The next stage was to extend the consideration of these potential indicators of liminality across the full transcripts for the first seven respondents.

4.2.1: Pausing

The silent pause lengths in the transcripts of the first seven respondents were analysed. There were 607 timed pauses of 1s or longer in the transcripts of the first seven respondents. The distribution of these pauses is shown in Table 2.

Length of pause	Number of pauses	Percentage of all pauses 1s or longer
1 - 1.9s	277	46%
2 - 2.9	162	27%
3 - 3.9s	68	11%
4 - 4.9s	36	6%
5 - 6.9s	25	4%
7 - 9.9s	23	4%
10s or longer	16	3%

Table 2: Distribution of pauses of 1s or longer

Many of the pauses in this study seem to be longer than the pauses reported elsewhere in the literature (see section 3.5.6).

There seems to be an approximate halving of the number of pauses every time we increase the pause length category by another second. This suggests that there might be over 500 untimed hesitations (pauses of less than 1s) in these first seven transcripts. If we add these in we can estimate that fewer than 10% of all pauses and hesitations lasted longer than 4s and fewer than 4% lasted longer than 7s. The unusually long pauses discovered in this study provided evidence that pausing might be a marker for liminality.

Of course, pausing behaviour differs between individuals. This meant that a criterion which had been elicited from the pause distribution of a group of individuals might not produce a fair sample of their utterances. Nevertheless, apart from m4 whose pauses tended to be very short, all of the first seven respondents had paused for longer than seven seconds on two or more occasions.

In order to confirm that pauses could be used as proxy markers for liminality evidence was sought as to the extent of the co-occurrence of pauses with phrases such as ‘I don’t know’. Not only were there a substantial number of instances of this, there were also a number of cases where a pause occurred both before and after the respondent saying ‘I don’t know’ or words to that effect and also cases where there was a pause, two ‘I don’t know’ statements separated by a pause, with a final pause at the end. These are shown in the tables below.

	pause before	Statement	pause after	Other indicators
f2	1.4s	‘but I don’t know ... how to ... do it’	2.3s	f2 says ‘It’s weird’ before first pause
f2	2.2s	‘but I don’t know why’	1.1s	sounding angry
f2	2.7s	‘I don’t know ... Harder to think about it in terms of ... things you can’t see’	4.1s	spoken in quiet voice hesitation
f2	8.2s	‘I’m, I’m really stuck’	2.9s	repetition
m5	12.2s	‘I don’t know’	11.7s	
m3	3.6s	‘I don’t know’	4.5s	momentary laugh
m1	5.5s	‘I don’t know’	2s	very quiet when speaking
m6	2.1s	‘I don’t know ... ummm’	4.3s	Non-lexical marker
m6	4s	‘Umm, I don’t know’	3.5s	Non-lexical marker
m2	2.7s	‘I doh, I don’t know why’	1.6s	repetition
m2	4.4s	‘No. I don’t know’	1.8s	
m4	2.6s	‘Don’t know’	2.9s	
m4	1.8s	‘Really don’t know’	1.3s	
m4	2.5s	‘Yeah ... I’ve no idea’	3.4s	Lexical marker

Table 3: ‘I don’t know’ statements both preceded and followed by a pause.

	pause before	first statement	Middle pause	second statement	pause after	other indicators of liminality
f1	2.8s	‘It’s weird I... don’t ... know’	2.5s	‘I’ve no idea’	3.5s	‘Weird’; Laughter with 2nd statement; hesitation;
m5	6.5s	‘I’m not sure’	1.9s	‘I don’t know, that’s it.’	(end of transcript)	
m6	3.2s	‘I don’t ... know’	13.4s	‘Don’t know, I mean’	4.2s	Whispers on first statement; repetition
m4	3.0s	‘No idea but’	2.3s	‘Don’t know that one.’	1.3s	

Table 4: Examples where a pair of ‘I don’t know’ statements where each is both preceded by and followed by a pause.

Sometimes the pausing and the ‘I don’t know’ statements are interwoven with other potential proxy indicators of liminality such as amusement and whispering. When asked ‘*So how does the surface, whatever the surface is, adjust its reaction force so that it does always balance... uh ...the weight of the thing lying on it?*’ m3 paused for 2.4s and then, sounding amused, said ‘I don’t know’. An 8.8s pause was filled with

‘umm ... umm’ before he stated ‘Well there’s no way for it to know OK but ... [3.5s] ... I don’t know any [spoken in a whisper] ... [3.1s] ... explain ... [7.1s filled with ‘umm’] ... I can’t remember, there’s a ... there was something that we said about ... [1.2s filled with ‘umm’] ... there’s a reciprocal ... [2.8s] ... that’s right ... [2.3s] ... but there’s no way for the bed ... or whatever surface it is ... to know ... how to adjust ... [3.6s] ... I don’t know’. This is then followed by a further 4.5s pause before I intervened.

The frequent co-occurrence of ‘I don’t know’ and pausing provides evidence that pauses are potential indicators of liminality. This is not to say that every pause marks liminality, some pauses were judged to be non-liminal. For example, after M1 has given an explanation of how a floor pushes back with the same force as the weight of the person standing on it he says ‘but’, pauses for 2.3s, says ‘yep’ and then pauses again for 5.3s before I intervene. The argument is that the ‘but’ expressed uncertainty about his explanation which he then reviewed during the first (2.3s) pause. ‘Yep’ was the sign that he was satisfied with his explanation. (It was subsequently realised that this use of ‘yeah’ or ‘yep’ to indicate the completion of a silent thought was an indicator of reflective self-dialogue.) The subsequent (5.3s) pause was the respondent, having completed what he wanted to say, waiting for a response. There were a number of such pauses which were termed ‘completion pauses’ because they indicated that the respondent had finished what they wanted to say and were waiting for the next stimulus.

Another example of a completion pause is when M3 pauses to indicate completion particularly when he is in ‘conversation’ rather than ‘think aloud’ mode, *i.e.* when I intervened. For example, after I asked ‘*Why shouldn’t the bed know ... what the force*

on it is?' m3 pauses for 2.1s before replying 'Because the bed's not a conscious being'. He then pauses again. I wait 2.5s before saying '*OK'* which seems to release m3 to state 'so it's unable to ...know'. Another 6.4s pause ensues while m3 waits for a response. I eventually ask '*Could the bed in any way detect what's on it?'* M3 considers the question for 3.0s before replying 'No.' Another pause ensues. What is evident in this extract are pauses to consider my intervention interwoven with pauses while M3 waits, having completed an answer. There are many other examples of completion pauses in m3's transcript.

A third example of a completion pause is when M5 is explaining why forces must be balanced: 'it wouldn't push up ... any more than what you're pushing down because if it did then ... your arm's going go up somehow and ... [1.1s] ... and that can't happen ... [1.4s]'. The first pause seems to indicate a brief mental review of the statement made but the second comes after the statement has been completed to M5's satisfaction.

Completion pauses are most evident when the participant seems to feel that they are no longer in a think aloud monologue but in a dialogic conversation. For example, after I state '*The harder I push ... the harder it pushes back'* M5 replies 'Yep' and waits for my next remark. Later, when I ask '*Are there springs in the surface?*' m5 replies 'No' and waits. Completion pauses are another way of indicating that the other person may, if they wish, take a turn speaking.

When a respondent pauses because they are stuck they may not speak again before an intervention. This means that stuckness pauses could appear similar to

completion pauses. It may be necessary to distinguish between them using other indicators. For example, a phrase such as ‘I don’t know’ suggests that associated pausing is due to the respondent being stuck rather than thinking that they have successfully solved the problem. Furthermore, stuckness is usually associated with increasing hesitation and pausing and an increased rate of other disfluencies; completion pauses usually occur after relatively fluent segments of speech.

Another type of pause that seemed arguably non-liminal was the pause that came about apparently while a memory was being accessed. For example, M3 has been asked by myself about an experiment he did in class involving springs. He replies ‘err ... yeah ...It ... err ... [5.4s] ... That was with the ... stress and strain ... Umm ... Oh God ... That was ... err ... [8.5s] ... can’t remember the way we worked it out’. The phrase after the pause tells us that during the pause was trying to access a memory. It is possible that the memory was harder to access because of liminality but it does not seem likely that all moments of forgetfulness can be explained by invoking liminality and therefore this pause was not characterised as liminal.

It was therefore concluded that a pause could be used as an indicator of liminality in the understanding that liminality might exist without a pause and that a pause might indicate something other than liminality but the presence of pausing increases the chance that the respondent is experiencing liminality. Thus pausing behaviour might be used by an analyst to diagnose liminality in the same way and with the same caveats as a doctor might use a raised temperature to diagnose a disease.

Specifically, where a pause indicates liminality it seems to be linked with the respondent becoming stuck.

4.2.2: Laughter

There were only 21 instances of laughter or amusement coded in the first seven transcript not all of which were clear and some of which seemed to be caused by stimuli external to the study. Nevertheless, eight of these codings were associated with the use of the phrase ‘I don’t know’:

- F2 laughs when she says:
    - ‘I don’t know’;
    - ‘I’ve no idea’;
    - ‘I’m just not seeing the answer’;
    - ‘I’m, I’m really stuck’
- M2 laughs when he says ‘I’ve no idea what I’m talking about’;
- M3 sounds amused, or laughs briefly, when he says:
    - ‘I don’t know’
    - ‘I don’t know’;
- M4 laughs when he says ‘I don’t know how’;

Since liminality has also now been associated with pausing, the co-occurrence of laughter with a long pause was also investigated:

- One of f2’s laughs occurred just before a pause of 11.6s
- One of m3’s laughs occurred just before a pause of 8.8s
- One of m6’s laughs occurred just after a pause of 8.8s

This suggested that laughter could be an indicator for stuckness. This was unexpected. The literature review had suggested that liminality was a time of doubt and uncertainty, of frustration and stuckness. One interpretation could be that this was defensive or nervous laughter prompted by an attempt to reduce the tension the respondent felt.

There were two other examples of laughter that were considered worthy of note.

- M4 (2m 2.2s): ‘I think it’s ... [1.6s] ... ‘Cause I ... after what, after time they balance out but instantaneously they’re not ... errr ... [2.8s] ... balanced ... ‘cause ... the dog ... is the bed norm ... normally isn’t acting up, pushing up on anything ... But then when it all lies on it, the bed push ... harder up ... to make, so the dog doesn’t fall right the way down and then it will ... eventually balance out like ... bit like drag ... and acceleration ... like when you’re falling the drag is lower and as that increases then it balances. ... But it’s a lot quicker. ... That’s my answer [Laughs]
- M6 (3m 25.2s): ‘Because it’s got [laughs] ... [2.6s] ... It could be ‘cause it’s got springs in the mattress hasn’t it? which have a ... which were pushing up ...’

This laughter seemed to be in response to solving the problem as if it were prompted by relief at escaping liminality or triumph at achieving the transformation. This would later be coded as a ‘possible breakthrough idea’ (see section 5.1.8).

There were also laughs which do not seem to act as proxy markers for liminality including f2 laughing as she does a calculation (‘hundred divided by twenty five or ... [2s] ... four ... so each spring ... [laughs] ... has ... four newtons ... that is err applied

to it') and m3 laughing in response to a redirection: 'OK We're not going there are we'; [m3 laughing] No. Just in this sense it should always be equal to the weight]'

There were therefore two ways in which laughter was interpreted as an indicator for liminality: to indicate stuckness and to indicate a 'possible breakthrough idea'.

4.2.3: Lexical fillers as thought initiators

Two categories of fillers were transcribed. Non-lexical fillers such as 'umm' or 'err' indicate pausing and were interpreted as such. Lexical fillers are words such as 'so', 'well', and 'yeah'.

Over 120 lexical fillers in the transcripts of the first seven respondents were scrutinised to assess to what extent they co-occurred with 'I don't know' phrases or long pauses. Just 17 examples of co-occurrences were discovered, nearly half of them from just one respondent.

However, a more careful scrutiny of the words used suggested that there were patterns although there were individual differences in how the respondents used them (and considerable differences in their frequency of use).

For example, the words 'so' and 'OK' and 'right' often occurred after a pause and before an utterance.

- M1: 'so ... [9.2s] ... So ... The weight of the ... dog down or the thing down'
- M5: '... [8s] ... OK so you push down on the surface'

- M5: '... [6.4s] ...Gosh ... [9s] ...'
- M5: '... [7.2s] ... OK. So ...'
- M5: ' ... [17.5s] ... Right. So. ...'
- M5 : '... [11.5s] ...Right, so ...'
- F2: '... [4.5s] ... Well, gravity's ... always going to be acting on him , 'cos he's on earth'

The interpretation made was that this indicated the respondent initiating a thought. Sometimes, as in the M1 example above, it seemed that the word was used in a failed attempt to initiate a thought. Other examples of this included:

- M1: 'so ... [5.5s] ... I don't know'
- M1: 'so umm ... [6.3s] ... I don't know how to apply that though ... to this ... to that'
- M2: 'So ... [3.8s] ...'
- M5: 'so ... [3.1s] ... yeah[4] ... I don't I don't really know how to ...'
- M3: 'Err well it ...sinks but that's the mattress ... umm ... [7.2s] ...'
- M6: 'So ... [3.2s] ...'

Sometimes the thought initiation failed only for a while

- M1: 'So ok ok ok so that would be ... [2.3s] ... a push, person is pushing ...'

Of course there were times when the word 'so' was used as a synonym for because:

- M1: 'So because whatever is on it has a weight pushing'

[4] This is later interpreted as an example of reflective self-dialogue suggesting that the silence after the pause might not indicate the failure to have a thought but the failure to utter a thought.

Another lexical filler was the word ‘like’. This is currently a common filler in teenage speech and it usually seemed to have no more meaning than ‘umm’ or ‘err’:

- M1: ’I don't know what wood’s made out of wood, it’s like, wood, innit’;
- M5: ‘There’s no ... [1.9s] ... forces, like, going in any other direction’;
- M4: ‘[The springs] will go to a certain ... like ... reduced size ... like ... length ... to support the weight of the dog’;
- F2: ‘Like I don’t think of the, like ... thing is adjusting’

4.2.4: ‘Yeah’ as a lexical filler

Another lexical marker seemed to be the word ‘yeah’. This was, of course, sometimes the response to a question posed by myself, as interviewer, although the response in such a case was more often ‘yes’. But ‘yeah’ was frequently used after a pause.

Sometimes the pause was preceded by a marker suggesting thought initiation:

- M1: ‘So ... [2.1s] ... Yeah’
- M3: ‘so ... [1s] ... yeah, every action has an equal and opposite reaction’
- M5: ‘so ... [3.1s] ... yeah ... I don’t I don’t really know how to ... go about this one’

This suggested that a thought had been initiated that was occurring during the following pause. The ‘yeah’ represented the endpoint of the thought.

In other cases the interpretation was that the pause had been used to evaluate a previous suggestion. For example:

- M4: ‘I don’t know ... [2.5s] ... Yeah ... I’ve no idea’

This was interpreted as M4 suggesting to himself that he was stuck, silently evaluating that suggestion and then confirming that he was indeed stuck.

In other examples the respondent reflects upon an idea:

- M4: ‘Well, the spring would ... extend then it would stop ... extending ... ‘cause of the tension upwards on the springs ... [3.7s] ... Yeah’
- M5: ‘Well it’s got springs ... [4.3s] ... Yeh so the springs have got ...’
- F2: ‘we can infer that ... there’s the same pushing up ... [3.5s] ... Yeah’

Thus the lexical filler ‘yeah’ appeared to mark a silent reflection during which the respondent was engaging in a dialogue with themselves; this was therefore coded as ‘reflective self-dialogue’.

4.2.5: Whispering or muttering

Whispering or muttering or a marked reduction in volume were noted on only 18 distinct occasions in the first seven transcripts. These included:

- M1 whispered saying ‘I don’t know’
- F2 whispered shortly before a pause of 10.7s
- M2 ‘almost’ whispered when saying ‘so I’ve no idea what I’m talking about’
- M3 whispered when saying ‘I don’t know any...’
- M6 whispers either side of a 10s pause

- M6 also whispers when saying ‘I don’t ... know’ just before a 13.4s pause
- M6 also whispers just before a 4s pause followed by the statement ‘Umm, I don’t know’

This offered some evidence that whispering might indicate stuckness.

Alternatively there were times when whispering or muttering seemed to indicate reflective self-dialogue:

- M1: ‘... [1.4s] ... Is that? Oh. That’s right. ... [5.4s] ...’
- M2: ‘they’re ... no longer stable they’re being pushed in and they’re not, no longer in their ... regular position ... umm ... [3s] ... so then ... [1.5s] ... they push back ... [3.3s] ... [in a whisper] they get squished, they push back.’
- M2: ‘... [2.7s] ... [in a whisper] what does squishing mean? ... [1.1s] ...’

Finally there were examples in which the respondent reacted to a stimulus by repeating part of it in a whisper as if the whisper served to highlight what was considered relevant:

- M1: ‘[Reads the stimulus] How does the bed adjust its reaction force so that it always balances the weight of the thing lying on it? ... [in a whisper] How does the bed adjust its reaction force?’
- M4 whispers while reading key words from the stimulus: ‘Bed adjusts ... balance ... the weight’
- M6: ‘[Reads the stimulus] How does the bed adjust so its reaction force is always balanced to the weight of the thing lying on it? ... [whispers] How does it adjust the thing ...’

- M1: ‘[Responding to the question: *Can you apply that idea of a dog on a bed or a meerkat on a bed to standing on a floor?* whispers] standing on a floor, ok’

It was concluded that whispering or muttering could be used as an indicator of liminality but that three different things might be indicated. It might indicate stuckness, it might indicate reflective self-dialogue, and it might indicate a strategy of highlighting or focusing on selected part from a stimulus.

4.2.6: Co-occurrence of repetitions with ‘I don’t know’

The connection between repetition and stuckness was evidenced in the same way as with long pauses by the incidences of repetition whilst expressing the phrase ‘I don’t know’ or words to that effect. This happened on a number of occasions:

- M1: ‘I don't know ... I don’t know’
- M2: ‘Every action has an equal and opposite reaction ... [2.7s] ... I doh, I don’t know why’;
- M2 when he says ‘I’m sure there is an explanation, I’m not saying there’s not. I just ... I, I’m not, I don’t know’;
- M4: ‘I don’t know how ... science [laughs] ... I don’t know really ... umm ... yeah ... Really don’t know ... [1.3s] ...’
- M4 also said: ‘So when you’re pushing down on the ground ... with a thousand newtons it will push back up ... a thousand newtons ... but I don’t know how’
- M5: ‘I don’t I don’t really know how to ...’

- M6 repeated the words ‘the floor’ in a whisper before saying ‘... [4s] ... Umm, I don’t know’

There were also examples in which repetition was associated with the opposite of stuckness, moments of realisation. At the times the respondent often sounded excited. Usually they spoke more rapidly than normal:

- M1: ‘No it isn’t, no it isn’t, it isn’t, it isn’t’
- M1: ‘Yeh. OK. Ok ok so ... there will, ok, so the force pushing down on the spring’
- M1: ‘So ok ok ok so that would be ... [2.3s] ... a push, person is pushing ... downwards so ... [1.8s] ... downwards, say a force of, say the dog, the dog’s pushing downwards with a force of a hundred newtons on the Earth’
- M1: ‘so ... OK ok so if the floors made out of wood there's loads of ...’
- M2: ‘Newton’s ... one of Newton’s laws is each ... each action has an equal and opposite reaction, so the forces acting on him, he’s got his weight’
- M2: ‘I’m not sure why but I just know that ... it does, it doesn’t adjust its reaction it just happens, Newton’s ... [1.7s] ... Laws’
- M2: ‘the force up depends on the force down so you can put anything on the bed and it will it will it will have an equal force up’
- M2: ‘See it can’t detect it, it’s, it’s not got anything to process ... detecting it’s ... it can’t adjust either’
- M4: ‘‘Cause I ... after what, after time they balance out but instantaneously they’re not ... err ... [2.8s] ... balanced ... ‘cause ... the dog ... is the bed norm ... normally isn’t acting up, pushing up on anything’

- M4: ‘‘Cause there’s, there’s less ... [1.1s] ...Grav ... like .... well grav ... the force of gravity isn’t as much which means the tension won’t be ... as much’
- M4: ‘Well the foam .... acts ... like a spring ‘cause when you ... it’s like a sponge so that ... so when you, when you have like a sponge that you wash you squeeze that, then it will go back to its original size just like with the s, the foam’
- M5: ‘It’s not like it needs the springs it just needs to, needs something there... to stop you from falling through’
- M6: ‘Not no not like not like a spring’
- F2: ‘and it’s the spring, it’s the spring sort of ...uncoiling and getting back to its original shape that pushes up on the meerkat’

Thus repetitions could indicate liminality either as a marker of stuckness or as a marker of excitement. It was speculated that this latter type of repetition might be associated with a moment of transformative learning or what was later coded as a ‘possible breakthrough idea’.

4.2.7: To what extent can vacillation indicate liminality?

There were very few examples of vacillation in the original corpus of transcripts of the first seven respondents. This may be because it is more difficult to identify because it may happen over a long period of time. This also makes it difficult to seek co-occurrences and to consider them on a fair basis with other more transient characteristics of an utterance such as pausing or repetition. It was not thought worth pursuing vacillation as a proxy marker for liminality.

4.3 Summary of indicators of liminality

Indicator	Interpretation as a feature of liminality	Alternative interpretation
Pausing	Stuckness	Indicating that respondent has completed utterance; waiting for interviewer to respond.
Laughing	Defensive laughing when stuck Triumphant laughter heralding a 'possible breakthrough idea'	Reaction to an amusing thought (for example the dog levitating)
Lexical filler for example, so, well, OK	Initiating thought or attempting to initiate thought	So: as a synonym for because
Lexical filler 'yeah'	Reflective self-dialogue	As agreement (but then usually 'yes')
Whispering or muttering	Stuckness Reflective self-dialogue Highlighting	
Repetition	Stuckness	As a marker of excitement, a possible breakthrough

Table 5: Summary of indicators of liminality

It has been established that there are some paralinguistic features of utterances that can act as indicators for characteristics of liminality. Most of these features have alternative interpretations, sometimes outside liminality; context is always important when interpreting these indicators.

Particular characteristics of the liminal experience that were highlighted by these indicators included stuckness, ‘possible breakthrough ideas’, initiating or attempting to initiate thought, highlighting, and reflective self-dialogue.

These markers were used to draw attention to segments of the transcripts for the next stage of the analysis process which was coding.

Chapter 5: Results 2: Coding

5.1: Characteristics of the liminal experience

It has been established that pauses, laughing, whispering or muttering, repetitions, and lexical fillers were potentially proxy markers for aspects of liminality. The phrase ‘I don’t know’ or words to that effect was also regarded as a marker for liminality. It was recognised that each of these markers might have interpretations other than liminality.

It had also been recognised that a focus on ‘I don’t know’ was a focus on just one feature of liminality: stuckness. There were other proposed characteristics with which the other markers might co-occur. Thus, the markers might be used to identify a part of the transcript that offered evidence of the experience of liminality that might then be coded.

The first seven transcripts were now microanalysed by being fragmented and each fragment was interpreted using the indicators and the codes developed. Where one of the markers was observed the context was carefully considered. If it was decided that there was evidence of liminality it was given a code which described what aspect of liminality it represented. For example, codes such as ‘preparation’, ‘stuckness,’ and ‘reflection’ were used. The code labels were intended to be drawn from the evidence and to describe it. But inevitably the label affected how I thought about the evidence and directed my attention towards aspects of the evidence. An

example of this, which involved a code being reinterpreted and relabelled following the retheorisation of liminality consequent upon the discussion and the second literature review, is shown in section 6.7.

Once the first seven transcripts had been coded, the method of constant comparison was initiated. This led to some codes being relabelled. For example, ‘reflection’ was relabelled as ‘reflection (self talk)’ and then again as ‘reflective self-dialogue’. As the labelling changed, the code evolved. Some codes merged. For example, ‘preparation’, a code for pauses, was merged into ‘cognitive challenge’ which had been used as a code for both pauses and repetitions. Some codes, such as ‘stuckness’, were split. Other codes were redrawn, and instances which had previously been coded as reflection were either moved into the new code or transferred elsewhere. During the second tranche of transcripts some new codes emerged and the process of constant comparison was used to reconsider the first tranche in the light of these new codes. This process of comparison and the relabelling, merging, and division of codes continued through the second tranche of transcripts.

Table 6 shows the codes which had emerged and survived at the end of the empirical stage of this study. These are the codes which are discussed in detail in this chapter and the next. The descriptions in the table are not intended to be formal definitions but guides.

Label	Description of code and its scope	See
Brick wall[5] stuckness	This is typically characterised by a single long pause lasting four seconds or longer.	5.1.1 6.6.1
Boggy ground stuckness	This is typically characterised by a period of pauses lasting between one and three seconds alternating with vocalised utterances	5.1.2 6.6.2
Reflective self-dialogue	This refers to a pause sometimes preceded by a marker of thought initiation such as the word ‘so’ and often followed by ‘yeah’ during which the respondent appears to be asking questions of themselves (and answering them).	5.1.3 6.4
Liminogenesis	This refers to the period immediately after a cognitive challenge. Sometimes the challenge is repeated in a modified form. Liminogenesis is typified by a long pause.	5.1.4
Initiating thought	This refers to the use of a lexical filler such as ‘so’ or ‘well’ which seemed to be associated with the articulation of a new thought although there were times when this thought was not articulated, for example when ‘so’ initiated reflective self-dialogue	5.1.5
Clinging to certainty	This was used as a label to code when respondents articulated what they were certain of.	5.1.6
The moment of truth	This described a moment when the respondent appeared to understand what was required even though they might not yet be able to solve the challenge. This could either involve the recognition that there is a problem or the ability to articulate what that problem is or both.	5.1.7
‘possible breakthrough ideas’	These were moments in which the respondent appeared to achieve a breakthrough in their thinking. They were typically preceded by repetitions or laughter; some were marked by an overt exclamation such as ‘I’ve got it’.	5.1.8 6.5

Table 6: Descriptions of codes used

[5] Following the retheorisation of liminality in section 6.7, this code was relabelled as ‘treading water stuckness’.

Three codes that had been established in the first seven transcripts were reconsidered when the full body of transcripts was examined. These were ‘vacillating’, ‘exploratory thinking’, and ‘groping through the fog’. There seemed insufficient evidence to support ‘vacillation’ as a code. Nevertheless, because one of the characteristics of liminality mentioned in the literature review is oscillation, and because the code of vacillation resonated with oscillation, this code is mentioned below. ‘Exploratory thinking’ was also a feature of ‘possible breakthrough ideas’ and boggy ground stuckness and was therefore disaggregated and subsumed into these categories. However, the use of seemingly deliberate exploratory thinking was reinterpreted as a strategy and is listed with the strategies below. ‘Groping through the fog’ was reinterpreted as ‘boggy ground stuckness’ and examples of its occurrence were recoded.

5.1.1 Brick wall stuckness

The co-occurrence of pauses with the phrase ‘I don’t know’ or words to that effect as established in the last chapter (section 4.2.1) suggested that pauses were indicators of stuckness. However, closer scrutiny suggested that there were two characteristic patterns of pauses. Sometimes there was a single long pause; at other times a series of shorter pauses broken with fractured utterances. My interpretation was that there were two types of pause. The first was like coming to a halt, as if the respondent had metaphorically hit a brick wall in their thinking; it was therefore labelled ‘brick wall stuckness’. The metaphor I used for the second was of a person trying to walk through boggy ground, stumbling and falling, then picking themselves

up and walking for a few steps before falling again. This was coded as ‘boggy ground stuckness’.

Sometimes brick wall stuckness occurred immediately after a cognitive challenge. The following examples came after the third stimulus had been presented.

- M6: ‘[Repeating extracts from the stimulus in a whisper] How does it adjust the thing ... [1.4s] ... balances the weight of the thing lying on it ... [10s] ...’
- F2: ‘... [10.4s] ...hmm ... [6.4s] ... That’s really weird. ... [3.9s] ...’
- M16: ‘... [10s] ...Well, every force has an equal and opposite reaction in the opposite ... direction ... of the same type. Umm ... [whispering] How does it adjust its reaction force so that it always balances ... [normal voice] So the weight acting [writing] on down on it ... what was it? 100 newtons ... so the bed is ... so the bed has to exert an equal force, a force in the opposite direction ... [19.7s] ...’
- M17: ‘... [10.7s] ... Balance the ...’

Other long pauses indicating stuckness came after other cognitive challenges, for example when I intervened to ask a question:

- M1: ‘... [6.4s] ... The reaction force changes ... [1.5s] ... due to Newton’s Third Law ... so .... [9.2s] ... So ... The weight of the ... dog down or the thing down’.
- M3: ‘... [2.4s] ... I don’t know ... errm ... errm ... [8.8s] ... Well there’s no way for it to know OK but ... [3.5s] ... [almost whispering] I don’t know any... [3.1s] ... explain ... umm ... [7.1s] ...’
- M8: ‘The ... [12.6s pause punctuated by mutters ‘I’m not, I’m not’ and ‘so’] ...’

- M13: ‘[In response to the question *So how does it know how hard to push back?*] ... [24s] ... No ideas ... Dunno.’

In other examples the respondent gets stuck later during the liminal experience:

- M1: ‘... [5.5s] ... I don’t know ... [2s] ...’
- M1: ‘So ... [6.9s] ... [very quietly] I don’t know ... [2s] ...’
- M1: ‘so umm ... [6.3s] ... I don’t know how to apply that though ... to this ... to that ... [1.7s] ...’
- M2: ‘Umm I, I don’t really know ... the rest of this one ... [5.5s] ...’
- M3: ‘... [3.5s] ... [almost whispering] I don’t know any ... [3.1s] ... [normal voice] explain ... umm ... [7.1s] ...’
- M4: ‘I don’t know ... [2.5s] ... Yeah ... I’ve no idea ... [3.4s] ...’
- M5: ‘... [3.4s] ... so ... [3.1s] ... yeah ... I don’t I don’t really know how to ... go about this one’
- M5: ‘... [6.5s] ... I’m not sure ... [1.9s] ... I don’t know, that’s it.’
- M6: ‘... umm ... [3.2s] .... I don’t ... know .... ummm .... [13.4s] ... Don’t know, I mean ... [4.2s] ... It ...’
- F2: ‘Ye-ah ... I’m, I’m really stuck [laughs] ... [2.9s]’
- F2: ‘... [7.5s] ... I don’t know what else ... to do ... [7.4s] ...’
- F2: ‘... [9.6s] ... I’m not sure’.
- F2: ‘I have no idea ... [14.7s] ... I don’t know.’
- M12: ‘No. Don’t even know how to answer that. ... [8.7s] ...’
- M16: ‘... [13.1s] ... Don’t know. ... [7.1s] ...’
- M17: ‘Would it be ... I’m completely changing [laughing] my answer here ... would it be something between ... the atoms [gesturing with hand] ... as you ...

try to push harder ... if, if it, if the table didn't push back your atoms would get closer which causes ... more of a ... a ... repel from ... the atoms which ... I'm not sure ... [11.7s] ... That's not, that's not right is it?'

- F2: '... [2.8s] ... It's weird I... don't ... know ... [2.5s] ... I've no idea [laugh] ... [3.5s] ...'

The long pauses in these examples suggested that thought had become paralysed. Sometimes there was no further response until I intervened to ask a different question, offer a suggestion or to terminate the interview. But in most cases the respondent did continue after the pause:

- M5: '.... [12.2s] ... I don't know ... [11.7s] ... Right, so ...'
- F2: 'I'm just not seeing the answer [laughs] ... [11.6s] ... So when nothing's on it ... it's pushing up with zero newtons'
- M12: '... [12.8s] ... I don't know how it adjusts its reaction force. ... The springs? ...'
- M5: [After I ask how a surface can 'know' how much reaction force to apply] '... [8.1s] ... It doesn't. What it's doing is it's reacting to what, what force is going on top of it.'
- M11: '... [5.2s] ... The bed ... It, the reaction force isn't actually like, the bed doesn't have to do anything, any surface will do that... '
- M12: 'Err ... [9.6s] ... I wouldn't have thought it adjusts a reaction force but ...'

In the first two examples M5 and F2 recover after long pauses. In the third example, M12 breaks the pause to express his difficulty but then guesses at a potential solution. In the remaining examples the respondents recover from long pauses to

question the terms of the stimulus. In each of these cases, therefore, there is evidence that thought has been occurring at least at some time during the pause.

5.1.2: Boggy ground stuckness

After having paused and recovered, some respondents then paused again. In a number of cases a pattern of alternating pausing and recovery was sufficiently distinctive to receive a separate code: boggy ground stuckness. For example:

- M15: '... [3.7s] ... By ... pushing the force up like ... it spreads the weight across it or something? I don't know ... [5.9s] ... Just ... whatever pushes down it pushes back up on it.'

There were a variety of scenarios for boggy ground stuckness:

- M13 starts with brick wall stuckness and, with a stumble on the way, finishes with a successful idea: '[24s] ... No ideas ... Dunno. ... [3.2s] ... Is it to do with like .... where the ... like say it has four legs, the bed ... and the things there ... the force is .... exerted ... across all four legs in a way ... and ... it equals out?'
- M13 starts with brick wall stuckness, has an idea, and then returns to the brick wall: 'No. I don't know. ... [13.2s] ... It ... [6.4s] ... It's just equal and opposite, isn't it? Don't know why. ... [7.1s] ...'
- M8 travels in a circle: '... [8.9s] ... Well the ... there must, there's sort ... well is ... there is no ... motion ... so ... technically ... technically there's no acceleration on either ... part is there ... so ... but the forces are still, the forces are balanced ... [3.6s] ... And acceleration is a component of force so it must be something to do with the acceleration ... cause I, cause that, that, that just

can’t ... change ... so ... [3.2s] ... I don’t know, so if it comes into contact with the bed ... then ... if I put my hand on this desk ... so the ... I don’t know what it is about the desk that stops my hand going through, you know, apart from its mass, the mass being resistance to acceleration, you know ... so ... [6.1s] ... I don’t know, maybe it’s ... [4.3s] ... Except there must be some kind of, I don’t know what acceleration but there has to be some kind of acceleration’

- M6 is moving through boggy ground but his ideas start to peter out and he becomes stuck: ‘... [2.1s] ... I don’t know ... umm ... [4.8s] ... Let’s see ‘cause ... umm ... [5.3s] ... There’s ... I don’t ... the spring ... the bed has springs ... and ... [2.5s] ... it has ... umm ... errr ... [14.9s] ...’
- M3 has an idea but rejects it: ‘[2.4s] ... [sounding amused, almost pleading] I don’t know ... errrm ... errrm ... [8.8s] ... Well there’s no way for it to know OK but ... [3.5s] ... [almost whispering] I don’t know any... [3.1s] ... explain .... umm ... [7.1s] ... I can’t remember, there’s a ... there was something that we said about ... ummm ... [1.2s] ... there’s a reciprocal ... [1.2s] ... that’s right ... [2.3s] ... but there’s no way for the bed ... or whatever surface it is ... to know ... how to adjust ... [3.6s] ... I don’t know [possibly a momentary laugh] ... [4.5s] ...’
- M3 struggles for a long time: ‘According to Newton’s Third Law ... Umm ... [3.2s] ... every action ... No That’s ... Err ... That. They should be ... equal ... [2.9s] ... and they work in pairs ... [1.8s] ... so ... [1s] ... yeh, every action has an equal and opposite reaction ... so that ... action is the weight of down on the bed ... so the equal ... and opposite reaction ... has to be the bed pushing back on the dog to hold it up otherwise it just ... go through it [laugh?] ... [1.8s] ... uhh so it has always equal be equal to whatever is on it at the time

... [1.6s] ... but ... unless you take into relation potential stress where something breaks if there's too much force on it ... [1.9s] ...'

- M6 struggles to keep going until the laugh heralds the arrival of an idea: '... [1.4s] ... So ... [3.2s] ... By balance it is, is, all it is off, all it's trying to say is ... [1.6s] ... How it ... [1.4s] ... Keeps it how the force is actually pushing back off of it ... [1.4s] ... OK ... ummm .... [5.6s] ... Well ... [3.7s] ... Because it's got ... [laughs] ... [3.6s] ... It could be 'cause it's got springs in the mattress hasn't it?'
- M1 appears to achieve a breakthrough but gets bogged down as he tries to explain it: 'So ok ok ok so that would be ... [2.3s] ... a push, person is pushing ... downwards so ... [1.8s] ... downwards, say a force of, say the dog, the dog's pushing downwards with a force of a hundred newtons on the Earth ... [4s] ... and the Earth's pushing back up with 100 newtons as well but you don't see the Earth move .... because 100 Newton's compared to however ... much the Earth ... has a mass of because obviously it doesn't have a weight ... [2s] ... you won't notice it ... but ... [2.3s] ... yep ... [5.3s]'
- M5 appears not to be able to think outside the channel of his thoughts: 'you can maybe think of the bed's frame instead ... so that it wouldn't have springs in it, it would just be the ... surfaces that prevent from falling ... to the centre of gravity, the centre of the Earth ... [10.2s] ... so the bed doesn't want to push back on it any more than it has to do so to keep it from moving ... so it wouldn't pushback... on the dog with more than a hundred newtons'

In a number of cases, boggy ground stuckness ends in brick wall stuckness:

- M2: ‘so I’ve no idea what I’m talking about [laughing] ... err ... [1.4s] ... they push back with ... [2.4s] ... the same amount of force that ... [2.4s] ... is put down on them to keep ... their position ... [2.3s] ... No idea ... [8.8s] ...’
- M3: ‘Well there’s no way for it to know OK but ... [3.5s] ... I don’t know any [almost whispering] ... [3.1s] ... explain ... umm ... [7.1s] ...’
- M4: ‘... [4.6s] ... How does the bed adjust its reaction force? ... So. It’s always balanced ... the weight of the ... thing lying on it ... [3s] ... No idea but ... Umm. ... [2.3s] ... Don’t know that one. ... [1.3s] ... I think that it’s... yeah ... no ... I dunno’
- M6: ‘I don’t know ... umm ... [4.8s] ... Let’s see ‘cause ... umm ... [5.3s] ... There’s ... I don’t ... the spring ... the bed has springs ... and ... [2.5s] ... it has ... umm ... err ... [14.9s] ...’
- M6: ‘Just this reaction force, say, it’s always balanced ... [3.6s] ... so what is balanced is the weight of the thing lying on it ... [3.2s] ... [whispering] I don’t ... know ... umm .... [13.4s] ... Don’t know, I mean ... [4.2s] ... It ... [2.3s] ...’
- F2: ’I guess when you apply a bigger weight ... and it’s over a bigger area ... [2s] ... springs ... just ... take ... [1s] ... share it out between them ... [7.9s] ... It’s weird like I can see the answer in my brain ... [1.4s] ... but I don’t know ... how to ... do it’

5.1.3: Reflective self-dialogue

In the last chapter there were two indicators that suggested that there were pauses during which the respondent was conducting an unvoiced dialogue with themselves. Some pauses were sandwiches between ‘so’ (which often indicated the initiation of a

thought) and ‘yeah’; in general ‘yeah’ (when it was not used as the answer to a question) was taken to indicate the present of unspoken dialogic reflection. The other indicator was whispering or muttering. Although this could be used (often with repetition) to highlight key parts of a stimulus (see section 5.1.3), and although it was sometimes used when the respondent was stuck, there were occasions when it appeared to indicate that the respondent was engaging in reflective self-dialogue.

In these examples respondents used reflective self-dialogue to evaluate whether their answers were correct:

- F2: ‘[quietly] down is a ... hundred newtons ... [1.8s] ... hmmm ... Oh wait, but no ... ‘Cos gravity’s ... involved’
- F2: ‘So there’s five newtons ... pushing down [draws] ... [1.1s] ... and, since it’s stationary ... we can infer that ... there’s the same pushing up ... [3.4s] ... Yeah’
- F2: ‘each ... spring has to push up four newtons ... [1.7s] ... But wait ... [4s] ... Yeah’
- F2: ‘since it’s stationary ... we can infer that ... there’s the same pushing up ... [3.4s] ... yeah ... [5.6s]’
- M1: ‘Yep ... uuhhh ... [2s] ... No it isn’t, no it isn’t, it isn’t, it isn’t’
- M1: ‘... [1.4s] ... [muttering] Is that? Oh. That’s right. ... [5.4s] ...’
- M1: ‘you won't notice it ... but ... [2.3s] ... yep ... [5.3s]’
- M1: ‘then it it would probably crack a little bit because the pressure ... umm ... [4.2s] ... Yep ... [2.4s]’

- M2: ‘He’s not moving so he doesn’t have any air resistance ... [2.2s] ... or friction ... [6.1s] ... yeah I’d say ... he’d have his weight of a hundred newtons downwards’
- M3: ‘According to Newton’s Third Law ... Umm ... [3.2s] ... every action ... No That’s ... Err ... That. They should be ... equal ... [2.9s] ... and they work in pairs ... [1.8s] ... so ... [1s] ... yeh, every action has an equal and opposite reaction’
- M3: ‘there’s a reciprocal ... [1.2s] ... that’s right’
- M4: ‘Well, the spring would ... extend then it would stop ... extending ... ‘cause of the tension upwards on the springs ... [3.3s] ... Yeah’
- M5: ‘We’ve got the normal contact forces ... err... going directly upwards ... [11.5s] ... yeah, so you’ve got a normal contact force going up’
- M5: ‘the dog’s heavier so it’s going to push down with more force ... on the springs ... err ... [9.5s] ... yes so to stop the dog from falling through the springs they’re going to push up with the same force’
- M5: ‘Well it’s got springs ... [4.3s] ... Yeah so the springs have got’
- M11: ‘So it’s ... yeah ... so it’s the normal reaction and his weight.’
- M11: ‘Mmmm I don’t suppose the bed knows. ... It’s ... quite ... weird. ... The bed knows because of the amount of ... force it experiences ... Yes ... Because if there’s a different thing obviously there’s going to be a different amount of force ...’
- M12: ‘I wouldn’t have thought it adjusts a reaction force but ... because the reaction force is always there, it follows the object around ... so ... [7.3s; whispering; inaudible] ... [normal voice] Yeah, the bed doesn‘t adjust its ... the reaction force.’

In this example the respondents use reflective self-dialogue to assess whether there answers are complete:

- M5: ‘pretty sure that should be it ... [6.4s] ... gosh ... [9s] ... Yeah. I bet ... that’s it.’
- M15: ‘he’s obviously got his weight which is his mass times gravity. Err ... He’s got friction acting on him when he’s lying on it err like friction of the rug ... he’s got err the normal reaction of the bed pushing back up on him. ... Err ... [5.5s] ... [quieter voice] That’s about it. ... [2.3s] ... [Normal voice, smiling] He’s got his internal forces oh yes that’s about it, isn’t it? ... I think.’

Some respondents used reflective self-dialogue to decide whether or not they were stuck:

- M4: ‘I don’t know ... [2.5s] ... Yeah ... I’ve no idea ... [3.4s] ...’
- M5: ‘so ... [3.1s] ... yeah ... I don’t I don’t really know how to ... go about this one’.
- M6 seems quite definite about using an analogy between floors and springs until he has had a chance to consider it: ‘Not no not like not like a spring because there’s no when you push down will contract, like a table doesn’t move at all it just pushes back ... with a force ... ummm ... [9s] ... I think’.

Some respondents asked questions of themselves:

- M2: ‘[whispering] what does squishing mean?’
- M12: ‘The weight of air? The earth pushes back on him? Yeah’

Reflective self-dialogue seemed to provide evidence that thinking within liminality is not always an interior monologue but sometimes an internal dialogue. It seemed that the respondent had somehow split their consciousness into two or more parts and was engaged in a discussion.

5.1.4: Liminogenesis

The design of the ‘dog on the bed’ exercise is to present a learner with a cognitive challenge and to see how they respond to it. It was expected that the cognitive challenge would provoke a liminal experience. There was evidence for this happening in every respondent except for F4 and M15 who seemed to be able to solve the problem very quickly.

The main cognitive challenge was the third stimulus which asked how the bed could adjust its reaction force to adjust to the weight of whatever was lying on it. But my interventions also provided cognitive challenges. For those respondents who seemed to avoid the original challenge and so avoid liminality, I intervened to confront them again with the original cognitive challenge. Furthermore, if and when a respondent had solved the challenge, usually in terms of the springs in the mattress, they were asked to apply their new understanding to explain how a floor could react to people of different weights standing on it, or how a bench could react to different forces pressing down on it.

Characteristic features of the responses to a cognitive challenge were:

- Immediately or shortly after the challenge there would be a long pause

- Repetition of a key phrase from the challenge, often in a mutter or a whisper

In most cases the cognitive challenge of the third stimulus led immediately or very swiftly either to a long pause suggesting brick wall stuckness or to a hesitant response suggesting boggy ground stuckness. M8 did both, responding to the third stimulus, after a short time stuck in boggy ground, with a theory involving acceleration then, after I asked '*What's accelerating?'*, responding with a 17.5s pause suggesting brick wall stuckness. The evidence linking cognitive challenge and stuckness can be found in in section 5.1.1.

A different response to the cognitive challenge posed by the third stimulus, used by a number of respondents, was to restate the problem. This might be seen as a way of prevaricating, playing for time, postponing the entrance into liminality, akin to a strategy of avoiding the threshold or refusing the call. However, in every case where this happened the way in which the stimulus was repeated involved whispering or muttering which has already been proposed as evidence of reflective self-dialogue. Furthermore, in most cases the stimulus was not repeated verbatim; instead there was a focus on certain words or phrases. It is therefore proposed that the use of reflective self-dialogue, or the modified way in which the stimulus was repeated, acted as a way for the respondent to reanalyse the stimulus.

To illustrate this the original stimulus (*How does the bed adjust its reaction force so that it always balances the weight of the thing lying on it?*) was repeated by M4 as (in a mutter) 'Bed adjusts ... balance ... the weight'; focusing on the key words. M1, on the other hand, abbreviates the stimulus when repeating it and whispers 'How does

the bed adjust its reaction force?' M6 begins in a whisper and crescendos to a normal voice when, after reading the stimulus aloud in a normal voice, saying 'How does it adjust the thing ... [1.4s] ... balances the weight of the thing lying on it ... huh ... umm ... [10s] ...' He has replaced the names of the dog and the meerkat with the generic 'thing', the bed has become 'it' and he has omitted some of the words; he has thus created a less specific statement. Finally, although M16 repeats the stimulus verbatim, he uses pauses to fragment the stimulus into chunks, each chunk being a coherent part of the problem. This in itself is an analysis. He then pauses for ten seconds before saying: 'Well, every force has an equal and opposite reaction in the opposite ... direction ... of the same type. Umm ...' He then repeats the stimulus again but this time in a whisper: 'How does it adjust its reaction force so that it always balances ...' This final repetition is incomplete.

This shows that the repetition of the stimulus is not a strategy of postponement or delay but an attempt to understand the problem better. It has been included in the strategies section (5.3.1) below.

This study sought evidence for threshold avoidance. Both the repetitions mentioned above and the long pauses following the third stimulus might have been interpreted as strategies of procrastination but it has been suggested above that there are alternative interpretations which are consistent with the rest of the evidence. This left six respondents who responded to the third stimulus with neither a long pause nor a whispered repetition of the question. Of these, M2's response shows the pattern of ideas alternating with pauses that is characteristic of boggy ground stuckness. F4 gave an acceptable answer with very little delay; rather than avoiding the threshold

she appears to make a swift and smooth passage through the threshold without experiencing liminality.

M3, M8, M13, and M15 also gave swift responses although their responses did not correctly address the stimulus. From the point of view of a teacher they might therefore appear to be avoiding the threshold. However, there is no evidence that this is a deliberate strategy on their part. In each case I intervened to press them on the details of their answer and in each case they subsequently displayed stuckness:

- M3: '... [2.4s] ... I don't know ... umm ... umm ... [8.8s] ... Well there's no way for it to know OK but ... [3.5s] ... I don't know any... [3.1s] ...'
- M8: 'The ... [12.6s pause punctuated by mutters 'I'm not, I'm not' and 'so'] ...'
- M13: '... [3.7s] ... By ... pushing the force up like ... it spreads the weight across it or something? I don't know.'
- M15: '[Laughs] Yeah. ... I, I guess ... it could err ... I don't know ... [2.8s] ... A ben, well, like, a bench doesn't know it but ... Newton's Law [gesturing with right hand] just explains it it doesn't like ... the bench won't like know Newton's Third Law and be like oh that's Newton's Third Law I'll follow this it just is like ... Newton's Third Law is what we as humans can use to explain ... what's happening here. [laughs, whisper] I don't know'.

There are therefore alternative interpretations of the utterances of these respondents. They could be seen as attempting to avoid the threshold by offering a response to a different stimulus; had they not been challenged they would have 'learned' something slightly different from what they were intended to learn; this could have been described as 'mimicry'. On the other hand they could be seen as

misperceiving the threshold and giving the best response they could. They were not intending to avoid liminality. After my intervention they saw the threshold correctly and were as stuck as those of their fellows who had seen it straight away.

This means that there is no evidence for deliberate threshold avoidance found in this study.

5.1.5: Initiating thought

The immediate response to a cognitive challenge was not the only context in which thoughts were initiated. Boggy ground stuckness was full of moments of thought initiation alternating with stuckness. There were some lexical markers, such as ‘so’, ‘well’, ‘right’, and ‘OK’ that seemed to indicate the respondent making a deliberate attempt to trigger a thought.

Some respondents used such triggers as a way of initiating thought after a long period of stuckness:

- M5: ‘... [7.2s] ... OK. So ... If you use ... if it’s another meerkat ... [1.5s] ... Same situation’.
- M5: ‘... [17.5s] ... Right. So. ... [1.9s] ... The rule is that... there’s always going to be an equal and opposite force dependent on what’s on it’.
- M5: ‘... [8s] ... OK so you push down on the surface’
- M5: ‘... [11.7s] ... Right, so ... [2.5s] ... to balance it out ... it’ll push back on the object with the same force that it the object’s pushing down on it so on the bed’

Other thoughts were initiated in the same way even without the long pause:

- M1: ‘Ok so ... the carpet here gives it a little bit of buoyancy’
- M1: ‘So ... The weight of the ... dog down or the thing down ... err ... [1.5s]’
- M2: ‘So ... [1.3s] ... every ffff ... every force’
- M5: ‘OK. So ... [2.7] ... What forces act on him? ... So I’m going to draw a free body diagram’
- M5: ‘So ... If that’s the dog ... We know that he’s got a weight of a hundred newtons’
- M5: ‘... so ... if the ... [1.5s] ... dog has an inertia’
- F2: ‘... [2.2s] ... OK, so ... First I know that it’s concerning forces ... [2.1s] ...’
- F2: ‘... [3.1s] ... So ... up is a hundred newtons ... [2.0s] ...’
- F2: ‘... [1.8s] ... So yeah ... I guess ... the bond is a constant then in that, in that ... scenario’
- F2: ‘Well ... you know there’s a normal force’
- F2: ‘well he’s not slipping off the bed’
- F2: ‘Well gravity’s ... always going to be acting on him’
- F2: ‘Well, it’s already ... been worked out’
- F2: ‘Well ... It can balance this’
- F2: ‘Well guess every action has an equal and opposite reaction’
- F4: ‘... [2.9s] ... Well, surely when the dog ... jumps off, there ... there’s no gravity downwards ‘cause there’s no object on the bed’
- M8: ‘... [2s] ... Well the, well the mattress sinks a bit’
- M8: ‘... [3.4s] ... Ok so I, it must be something to do with this, this, this idea that the bed is not’

- M8: '... [2s] ... Ah, so it's kind of like terminal velocity then ... I think, so ... the dog hits the bed, or well, sits on the bed'
- M8: 'So it, is it because of the displacement, is it displacing?'
- M12: 'Oohhh. Okay, they give ... the springs ... balance when you lie on the bed ... to ... provide an equal reaction force'
- M13: 'Is it to do with, so .... when the dog gets on it, it compresses the springs a set amount.'
- M15: 'Err ... so if we can assume that the ... it would be the same forces'
- M15: 'Yep ... so err ... that's because ... errr ... every force has an equal and opposite force'

There are times when what seems to be initiated is reflective self-dialogue. These are shown when a 'so' precedes a pause and a 'yeah' follows it:

- M3: 'so ... [1s] ... yeh, every action has an equal and opposite reaction'
- M5: 'so ... [3.1s] ... yeah ... I don't I don't really know how to ... go about this one'.
- M11: 'So it's ... yeah ... so it's the normal reaction and his weight ... and they're in balance.'
- M12: 'because the reaction force is always there, it follows the object around ... so ... [7.3s] ... [whispering inaudible] ... [normal voice] Yeah, the bed doesn't adjust its ... the reaction force'

There were occasions when the thought, if initiated, failed to be articulated

- M1: '... so .... [9.2s] ...'
- M2: '... [1.3s] ... so ... [2.6s] ...'

- M2: '... [2s] ... so ... [3.8s] ...'

There were times when the thought failed to arrive:

- M1: 'So ... [5.5s] ... I don't know'
- M5: '... [3.4s] ... so ... [3.1s] ... yeah ... I don't I don't really know how to ... go about this one'

Examples of boggy ground stuckness show repeated attempts to initiate thought:

- M5: 'OK. Anyway ... umm ... [4.7s] ... So ... my thinking would be that the bed has ... a maximum amount of force acting go back ...'
- M6: 'It ... [1.4s] ... so ... [3.2s] ... By balance it is, is, all it is off, all it's trying to say is ... [1.6s] ... How it ... [1.4s] ... Keeps it how the force is actually pushing back off of it ... [1.4s] ... OK ... umm .... [5.6s] ... Well ... [3.7s] ... Because it's got ...'

5.1.6: Clinging to Certainty

M1 and M5 started their responses to the first stimulus by stating what they knew:

- M1: 'uhh. OK. OK. ... So ... We already know that ... '
- M5: 'So ... If that's the dog ... We know that he's got a weight of a hundred newtons'

At other points in the transcripts there were examples of respondents taking care to distinguish between what was known and what was not known:

- M1: ‘uhh ... don’t think we can find out the magnitude but we know he’s ... going to have that in that direction’
- M2: ‘I’m not sure why but I just know that ... it does, it doesn’t adjust its reaction it just happens’
- F2: ‘I don’t know that atoms behave quite like springs ... But I guess if they did’
- M3: ‘but err ... [5.1s] ... I don’t know that’
- M8: ‘I don’t know ... I, I’m not sure ... but ... I would say ... probably’
- M12: ‘Yeh. That’s all I can really know.’

This was turned into a strategy (the ‘Edison’ strategy below) by F2 who felt that if she went through everything she knew at some stage she would come across something that would help. Examples include:

- ‘OK, so ... First I know that it’s concerning forces ... [2.1s] ... and ... I know an equation that means force times ... mass ... no’
- ‘err, I know ... the force... that the dog exerts ...’
- ‘I know it’s something to do with electrons’
- ‘I know it’s not really anything to do with Hooke’s Law’
- ‘All I know ... they’re made up of quarks which is probably irrelevant ... but still it’s a thing’

The interpretation behind the code ‘clinging to certainty’ was that making sure of what you know is a way of establishing security in a time of uncertainty.

5.1.7: The moment of truth

There were moments during the experiences of some of the respondents when they realised and articulated the fundamental issues leading to their cognitive challenge. This was coded as ‘the moment of truth’.

There seemed to be two stages to a moment of truth. First comes the recognition that there is a problem. In the second stage one is able to articulate what that problem is. Most of the respondents only provided evidence for one stage.

First stage:

- F2: ‘Like I don’t think of the, like ... thing is adjusting ... [1.4s] ... to ... a weight but it does’.
- M11: ‘I don’t suppose the bed knows. ... It’s ... quite ... weird’
- M3: ‘but there’s no way for the bed ... or whatever surface it is ... to know ... how to adjust’
- M13: ‘it can’t like ... tell what’s on it. ... It just knows ... it doesn’t know anything it’s just what .... pushing back the force which is exerted on it.’

Second stage:

- M1: ‘how it adjusts it's not like it is physically doing it ... because it is ... not alive ‘
- M3: ‘Because the bed’s not a conscious being’
- M11: ‘it doesn’t know it because it’s a bed, it can’t know stuff, but it obeys ... the law’ and later ‘it ... must in a way kind of know without actually knowing.’

- M12: ‘It’s not like a computer it just kind of runs on ... data rather than ... knowing things. I could lie on it [mutters] and it wouldn’t know it was me.’

Some respondents articulated both types:

- M2: ‘I’m not sure why but I just know that ... it does, it doesn’t adjust its reaction it just happens, Newton’s ... [1.7s] ... Laws’ Later he says ‘the bed doesn’t have any ... brain or thoughts ... so it doesn’t do it ... because it chooses to ... it does it because it has to’ and later still ‘the way that we’re describing it, it’s like it’s ... it’s choosing to do what it does ... [1.9s] ... But it’s not, it’s just abiding by the laws of Physics’
- M5: ‘obviously it doesn’t know, it’s not like it’s got a brain but’. There follow a few (mostly silent) seconds before he comes up with an original idea: ‘could it be to do with like inertia?’

5.1.8: ‘possible breakthrough ideas’

The analysis of repetitions in some of the transcripts suggested that this particular disfluency could mark a sudden breakthrough in thinking:

- M1: ‘No it isn’t, no it isn’t, it isn’t, it isn’t’
- M1: ‘err ... [4.9s] ... And then then ok so the bed is pushing back on whatever is on it’
- M1: ‘So ok ok ok so that would be ...’
- M8: ‘this, this, this idea’
- M17: ‘oh right ... right ... I’ve got it ...’
- M17: ‘if, if it, if’

- F2: ‘and it’s the spring, it’s the spring sort of ...uncoiling and getting back to its original shape’

These are disfluencies but in a different way from the hesitancies typical of being stuck. There is a sense of excitement. It is as if previously hesitant speech has become a stream of words which flow so fast that it becomes turbulent.

Repetition was one way in which a sudden breakthrough in thinking was marked. An alternative indicator was laughter:

- F2: ’So that’s how it adjusts! It’s just the springs. ... See, I was thinking about it in terms of electrons, I was ... totally off [laughs]’
- M6: ‘there’s a carpet ... but that’s not really floor ... ummm ... [8.8s] ... [laughs] ... Err ... [2s] ... It’ll be in the floor’.
- M4’ ‘that’s my answer [laughs]’.

There were two examples which involved both laughter and repetition.

- M6: ‘OK ... umm .... [5.6s] ... Well ... [3.7s] ... Because it’s got ... [laughs] ... [3.6s] ... It could be ‘cause it’s got springs in the mattress hasn’t it?’
- M17: ‘if, if it, if the table didn’t push back your atoms would get closer which causes ... more of a ... a ... repel from ... the atoms which ... I’m not sure’ [smiles]

However, in this second example the smile seems to indicate stuckness rather than excitement.

These recalled the excitement surrounding the achievement of solutions in insight problems, commonly known as ‘eureka’ moments. However, many of the realisations are small scale and solve only part of the problems. Therefore they were coded as ‘‘possible breakthrough ideas’’.

An analysis of the transcripts indicated that these might be the moments of transformative learning within the liminal experience. Some ‘possible breakthrough ideas’ did indeed lead to a breakthrough in the respondent’s understanding:

- M4: ‘‘Cause I ... after what, after time they balance out but instantaneously they’re not ... err ... [2.8s] ... balanced ... ‘cause ... the dog ... is the bed norm ... normally isn’t acting up, pushing up on anything ... But then when it all lies on it, the bed push ... harder up ... to make, so the dog doesn’t fall right the way down and then it will ... eventually balance out like ... bit like drag ... and acceleration ... like when you’re falling the drag is lower and as that increases then it balances ... But it’s a lot quicker. ... That’s my answer.’
- M6: ‘Because it’s got ... [laughs] ... 3.6s] ... It could be ‘cause it’s got springs in the mattress hasn’t it? which have a .,. which were pushing up ... that could be part of it but then that is not the normal contact force’
- M8: Ok so I, it must be something to do with this, this, this idea that the bed is not ... so ...there is some kind of ... movement ... of the bed ... when the dog, or the meerkat, sits on it ... so ... [2s] ... Ah, so it’s kind of like terminal velocity then ... I think, so ... the dog hits the bed, or well, sits on the bed, the, the surface of the bed is then ... compressed ... yeh and moves, moves down until the point when ... the resistance ... is great enough to ... balance out the forces so ...’

However, some of the realisations were fragile; they failed to stand up to scrutiny and were abandoned.

For example, some did not lead to new thinking but were recognitions that the old ideas had been erroneous:

- M1: ‘No it isn’t, no it isn’t, it isn’t, it isn’t’

These were ‘possible breakthrough ideas’ that could also have been coded as a ‘moment of truth’ (section 5.1.6)

Some were only partial insights:

- M1: ‘Yeh. OK. Ok ok so ... there will, ok, so the force pushing down on the spring ... the spring's going to have to push back up because it's not, because the spring isn't collapsing upon itself it’s going to push up because of the quality of the spring ...’
- M1: ‘So ok ok ok so that would be ... [2.3s] ... a push, person is pushing ... downwards so ... [1.8s] ... downwards, say a force of, say the dog, the dog’s pushing downwards with a force of a hundred newtons on the Earth ... [4s] ...’

Some led to a breakthrough that the respondent subsequently decided was incorrect or led nowhere:

- M1: ‘And then then ok so the bed is pushing back on whatever is on it ... so when some the thing on it changes it's ... mass or weight ... then the reaction force on it is going to change as well ... [1.2s] ... So ... [3.3s] ... the bed

[inaudible] is just whatever's on it, on top of it, it reacts to that ... [3.3s] ... I don't know ... I don't know.'

- M12 laughs and says 'Or the springs? ... [1.8s] ... No. Don't even know how to answer that'
- M17, having given an answer promising plenty of potential from the perspective of the teacher concludes 'That's not, that's not right is it?'

Some led towards a false understanding. Not all the 'possible breakthrough ideas' led to what the teacher might recognise as 'correct' physics (such as when M5 decides that the solution is 'inertia' or when M3 explains a labelled formal explanation which he seems to consider unsatisfactory in terms of an 'otherwise' teleological explanation).

These exceptions suggest that the difference between 'possible breakthrough ideas' and transformative learning is that, at the moment of the 'possible breakthrough idea', the learner believes that a breakthrough has been made. They often then proceed to test out their idea and they may then believe that they have not made a breakthrough. The observer, with a different perspective, may decide that the learner is mistaken in one or both of these beliefs. But the evidence reflects the learner's point of view, not the observer's. In other words, whether or not the 'possible breakthrough idea' is a learning transformation depends on criteria that the learner does not possess.

Typically the repetition or laughter preceded the articulation as can be seen in table 7 below:

	Evidence for 'possible breakthrough idea'	'possible breakthrough idea'
M1 (0m 43.7s)	No it isn't, no it isn't, it isn't, it isn't ...	... a hundred newtons [inaudible] ... he's really got a hundred newtons.
M1 (4m 4.4s)	And then then ok so	the bed is pushing back on whatever is on it ... so when some the thing on it changes it's ... mass or weight ... then the reaction force on it is going to change as well
M1 (7m 2.2s)	Yeh. OK. Ok ok so ... there will, ok, so	the force pushing down on the spring ... the spring's going to have to push back up
M1 (8m 54.4s)	So ok ok ok so that would be ... [2.3s] ...	... a push, person is pushing ... downwards
M4 (2m 2.2s)	Cause I ... after what, after time	after time they balance out
M6 (3m 25.2s)	Because it's got [laughs] ... [2.6s] ...	... It could be 'cause it's got springs in the mattress hasn't it?
F2 (14m 53.1s)	So that's how it adjusts! ...	... It just matches ... whatever electrons are pushing down
F2 (17m 59.0s)	and it's the spring, it's the spring sort of ...	... uncoiling and getting back to its original shape that pushes up on the meerkat ...
M8 (10m 15.4s)	this, this, this idea that the bed is not ... so ...	... there is some kind of ... movement ... of the bed ... when the dog, or the meerkat, sits on it
M8 (11m 34.3s)	'Perhaps it is, it is like that. So therefore ... Ah, so! ...OK. The mass of ...	... let, let's treat the bed like, I don't know, a fluid [laughs].
M12 (3m 23.1s)	[Laughs ... 4.5s] ...	Or the springs?
M12 (7m 38.6s)	Oohhh [smiles].	Okay, they give ... the springs .... balance when you lie on the bed ... to ... provide an equal reaction force ... so when you get on the bed you ... you know ...bounce ... a little bit ... for a few seconds
M17 (3m 6.6s)	So ... when ... oh right ... right ... I've got it ...	so when the object is on the bed ... it's got its springs underneath it ...'
M17 (4m 9.5s)	if, if it, if	if the table didn't push back your atoms would get closer which causes ... more of a ... a ... repel from ... the atoms

Table 7: 'Possible breakthrough ideas'

This suggests that the realisation of the ‘possible breakthrough idea’ came before it was articulated. Sometimes there was no noticeable time delay; at other times this delay was between about one second and nine seconds.

Traditionally ‘eureka’ moments are supposed to be sudden insights, arising ‘out of the blue’. However, in many cases it was relatively easy to follow the chain of thoughts leading to a ‘possible breakthrough idea’. For example:

- F2 has been using the Edison strategy to slowly piece together what she knows when a revelation bursts upon her: ‘if it’s like the dog lying over springs ... it’s a lot more ... over the springs ... [1.3s] ... So that’s how it adjusts!’
- Later F2 is exploring ideas about a spring ‘sort of ...uncoiling and getting back to its original shape that pushes up on the meerkat’. There is a 1.9s pause, then F2 says ‘So that’s how it adjusts! It’s just the springs.’
- M8 is exploring the idea that there is transient movement before the equilibrium occurs: ‘ it must be something to do with this, this, this idea that the bed is not ... so ...there is some kind of ... movement ... of the bed ... when the dog, or the meerkat, sits on it ... so .... [2s] ... Ah, so it’s kind of like terminal velocity then’
- M12 is using a frame by frame strategy in the first person to imagine himself moving on top of springs before he has his ‘possible breakthrough idea’
- M17 has been exploring ideas about springs before he says ‘I’ve got it ... so when the object is on the bed ... it’s got its springs underneath it ...’
- There was one example of serendipity. M8 is wondering about the dog moving downwards and uses the word displacement. In physics this can

mean a change in position but it can also be used in connection with the upthrust from a fluid which M8 had studied not long before the interview. This prompts M8 to say: ‘let, let’s treat the bed like, I don’t know, a fluid [laughs]’; the laughter and the repetition suggest that this is a ‘possible breakthrough idea’ event.

In other cases there was evidence of reflective self-dialogue suggesting that a train of thought leading up to the ‘possible breakthrough idea’ may have been taking place even though the thoughts were not being spoken aloud. For example,

- M1’s burst of denial ‘No it isn’t, no it isn’t, it isn’t, it isn’t’ follows ‘yep’ indicating reflective self-dialogue
- M1: ‘So ... [2.1s] ... Yeah ... [2.4s] ... So ok ok ok so that would be’
- M12 both whispers and says ‘yeah’ before laughing and saying ‘or the springs?’

This leaves a few occasions when it is more difficult to find a proximate cause of the ‘possible breakthrough idea’ thought:

- M5: ‘Umm ... [12.6s] ... Could it be to do with like inertia ... or something’
- M6: ‘‘Because it’s got [laughs] ... [3.6s] ... It could be ‘cause it’s got springs in the mattress hasn’t it? which have a ... which were pushing up ...’
- M16: ‘... [8.4s] ... Just cause ... Newton’s Law ... but ... ummm ... the springs, [smiling] there’s springs in the bed, I guess ... [13.4s] ...’
- M17: ‘... [6.5s] ... Would it be ... I’m completely changing my answer here ... would it be something between ... the atoms ...’

5.1.9: Assessing the potential of an idea

The fact that some respondents experienced a ‘possible breakthrough idea’ only to later reject it showed that they found it difficult to judge the potential of an idea.

Sometimes respondents even found it difficult to know whether they were stuck:

- M5: ‘I’m not sure ... [1.9s] ... I don’t know, that’s it.’
- M4: ‘No idea but ... Umm. ... [2.3s] ... Don’t know that one ... [1.3s] ... I think that it’s... yeah ... no ... I dunno’

When M4 says ‘I don’t know how ... science [laughs] ... I don’t know really ... umm ... yeah ... [1.1s] ... Really don’t know ... [1.3s] ... Is it ... Newton’s First Law pushing up. Every action has an equal and opposite reaction’ he appears to maintain that he is stuck even while continuing to pursue ideas.

A number of extracts could be interpreted in a way consistent with the idea that the respondents were trying to pursue an idea but ‘lost their way’ because they were unable to assess how ‘warm’ they were:

- M2: ‘The ideal position for an electron to be in ... [2.4s] ... I’d say it’s a fixed point around the ... around the proton ... [1.6s] ... so when they get pushed in ... [1.1s] ... they’re not in ... [2.3s] ... the point at which ... [2.9s] ... they’re stable ... [1.8s] ... they’re ... no longer stable they’re being pushed in and they’re not, no longer in their ... regular position ... umm ... [3s] ... so then ... [1.5s] ... they push back ... [3.3s] ... they get squished, they push back ... [1.6s] ... so I’ve no idea what I’m talking about ... err ... [1.4s] ... they push

back with ... [2.4s] ... the same amount of force that ... [2.4s] ... is put down on them to keep ... their position ... [2.3s] ... No idea'

- Despite having the idea about springs, M6 seems unable to progress: 'Let's see 'cause ... umm ... [5.3s] ... There's ... I don't ... the spring ... the bed has springs ... and ... [2.5s] ... it has ... umm ... errr ... [14.9s] ...'
- F2: 'it's just the electrons repelling one another ... when you push down on something ... That's the force that you're feeling ... in ... basic terms ... [2.1s] ... I have no idea ... [14.7s] ...'
- M12: 'Or the springs? ... [1.8s] ... No. Don't even know how to answer that.'
- M17: 'if, if it, if the table didn't push back your atoms would get closer which causes ... more of a ... a ... repel from ... the atoms which ... I'm not sure [smiles] ... [11.7s] ... That's not, that's not right is it?'

It is frustrating for a teacher to listen to these extracts. The learner is appears to be very close to the answer but they do not know it. Some respondents found it so difficult to assess the potential of an idea that they were more likely to come up with new ideas than to pursue it:

- After coming up with the concept of that the springs are compressed M1 pauses for 5.9s pause. During this pause he seems to abandon compression in favour of a new idea: equilibrium.
- M13 advances three theories but fails to pursue any of them.

As has previously been stated, there was evidence that during some of the pauses respondents evaluated their responses using reflective self-dialogue. Nevertheless there were times when this evaluation failed to tell them how close to the answer

they were. This might have been because they did not have a clear view of what the answer might be, although this was not the case for F2 who stated ‘It’s weird like I can see the answer in my brain ... [1.4s] ... but I don’t know ... how to ... do it’.

5.1.10: Summary of the key features of liminality

To summarise, the indicators established in the last chapter enabled the coding of a number of characteristics of liminality. Other characteristics also emerged from the microanalysis. These can be used to create a description of the liminal experience. The liminal experience is initiated when the threshold is presented by a cognitive challenge; although there was some evidence that some respondents might have failed to perceive the threshold there was no evidence of any deliberate attempt to avoid the threshold.

The respondents often became stuck during liminality: there were two types of stuckness observed. Different activities observed during liminality were: words indicating the initiation of thought, such as ‘so’ or ‘right’; clinging to certainty; and, in particular, reflective self-dialogue. Breakthrough realisations included moments of truth and ‘possible breakthrough ideas’ but many respondents found it difficult to assess the potential of their ideas.

Phase	Code	Typical indicators
Entering liminality	Liminogenesis	Pausing Muttering or whispering
Travelling through liminality	Initiating thought	Lexical marker for example, 'so', 'OK', 'well' etc
	Reflective self-dialogue	Muttering or whispering Lexical filler 'yeah' following a pause
	Brick wall stuckness	'I don't know' etc Pausing Laughing
	Boggy ground stuckness	Pausing
	Clinging to certainty	
	Assessing potential	
	The moment of truth	
Leaving liminality	Eureka and 'possible breakthrough ideas'	Repetitions Laughing

Table 8: Codes used to describe characteristics of the liminal experience

These codes can be used to create an interpretive map of the liminal experience as shown in this extract from the transcript of M1.

Transcript	Interpretation
[repeats in a whisper] How does the bed adjust its reaction force?'	The **whisper** indicates **reflective self-dialogue**. This suggests that M1 appreciates the **cognitive challenge**.
'Ok so. The bed can only have a reaction force equal to errr ... the weight of whatever's on top of it just in the opposite direction ... so when something of 100 newtons lies on it, it is going to have a reaction force of 100 newtons too ... [1.8s] ... when there's nothing on it, it will have ... zero reaction force ... umm ... [2.4s] ... assuming that ... counting the bed as in everything that's on the bed, the pillows and all of that, so that's going to have zero reaction force and when you put something of five newtons it's going to ... [1.2s] ... the thing is going to weigh down 5 newtons and whatever is going to push up is five newtons too ... [1.2s] ... to cancel it ...'	However, M1 starts his response without a pause. 'OK so' indicates that M1 is **initiating thought**. M1 then proceeds to **explain by describing**. The phrase 'to cancel it' suggests that M1 may be attempting a **teleological explanation**.
[Experimenter intervention] *How does the bed adjust its reaction force?*	
'... [6.4s] ...'	This pause suggests that M1 has now begun to acknowledge the cognitive challenge.
'The reaction force changes ... [1.5s] ... due to Newton's Third Law ... so ....'	M1 now **label**s his previous (**formal**) explanation.
'... [9.2s] ...'	Another long pause suggests he is aware that **his explanation so far needs improving**.
'So ... The weight of the ... dog down or the thing down ... err ... [1.5s] ...'	Again he tries to initiate a thought with 'so'.
'And then then ok so the bed is pushing back on whatever is on it ... so when some the thing on it changes it's ... mass or weight ... then the reaction force on it is going to change as well'	The repetition ('then then') suggests that this is a **'possible breakthrough idea'**. The 'ok so' suggests the start of a thought. However, the thought that excited him is just a description of the problem.

'... [1.2s] ... So ... [3.3s] ... '	He seems to realise that his revelation was a false dawn but it is questionable to what extent he is able to **assess the potential** of his ideas.
'the bed [inaudible] is just whatever's on it, on top of it, it reacts to that'	The inaudible word suggests that M1 is engaging in **reflective self-dialogue**.
'... [3.3s] ...I don't know ... I don't know ... I'm thinking that it's whatever's pushing down on the bed is gonna push back so that's ... how it adjusts it's not like it is physically doing it ... because it is ... not alive like the ... weight pushing down'	He recognises that he is **stuck.** 'I'm thinking' suggests exploratory thought. He is able to articulate his problem: the bed is not alive. This is a **moment of truth**.

Table 9: Extract from M1 showing codes being used to interpret the experience

In summary: M1 seems to recognise the scale of the challenge but his first response is to describe what happens rather than to explain it (although he may attempt a teleological explanation). After I intervene M1 is forced to confront the challenge and pass through the threshold. The pauses become longer. He has a 'possible breakthrough idea' but it seems to prove a false dawn. He becomes stuck but is at least able to articulate his problem.

5.2: Explanations

The 'dog on the bed' task starts with a straightforward physics problem of the sort that the respondents had encountered before in class: in effect it asks them to recall and apply Newton's Third Law of Motion, often paraphrased as 'every action has an equal and opposite reaction'. Thus all respondents, mostly sooner rather than later, realised that the dog was in equilibrium and that therefore the force up was equal in

size to the force down. The second stimulus was swiftly recognised as a highly similar problem; the only difference was in the numbers. The third stimulus then asked the respondents to explain how the bed adjusted the balancing force to match the weight of the object lying upon it. This was a new question to most of my respondents (judging from their responses only F4 and M15 might have considered this question before).

It is proposed below that a possible cause of the cognitive challenge and subsequent liminality apparently experienced by many of the respondents was a mismatch between the explanation they were able to offer and the explanation they felt was being required.

A number of different types of explanation were distinguished in the responses to this question:

- Explanation by decree
- Otherwise
- Describing
- Labelling
- Explanation by intention
- Explanation by design
- Teleological explanation
- Formal explanation
- Saving the phenomena explanation
- Material explanation
- Explanation within limits

Other explanations may be possible but they were not observed within this study.

It is not always possible to categorise explanations precisely. For example, M2 states ‘it doesn’t adjust its reaction it just happens, Newton’s ... [1.7s] ... Laws ... Every action has an equal and opposite reaction’. ‘It just happens’ sounds like an explanation by decree but M2 immediately cites Newton’s Laws. Is this therefore an explanation by labelling or, since he goes on to explain the law, is it a formal explanation for which he has used the label as a shorthand? Furthermore, in a number of cases the explanations were nested. For example, a respondent may be able to offer a material explanation for the dog on the bed in terms of the springs in the mattress but be unable to explain why a spring should always push back with the same force that it is being squashed with; for this last explanation the respondent might resort to an explanation by decree (because it does!) or by labelling (because the spring is elastic). Thus either explanation by decree of labelling have been nested inside the material explanation. This is not an inadequacy on the part of the respondents, all explanations rely on other explanations in a chain that ultimately ends in an explanation by decree of labelling just like dictionary definitions end in circularity.

It might be argued that each of these explanations is valid and that none of them are ‘better’ than others; indeed the ‘preferred’ explanation might very well depend on the context. Nevertheless, for these respondents in the context of this challenge some explanations seemed to be favoured. This was evidenced in two ways: firstly by the fact that, having achieved an explanation the respondent acted as if they were still unsatisfied and still experiencing liminality and continued to pursue another

explanation, and secondly by comments made by the respondent about an explanation they had offered.

Each explanation used by respondents in this challenge is discussed below. Where there is evidence as to how it was viewed this is also given.

5.2.1: Explanation by decree

Four respondents resorted to explanation by decree when they were unable to offer other explanations.

- F2, trying to explain the ‘dog on the bed’ problem in terms of electrons, stated ‘cause that’s just how electrons work.’
- F2: ‘the bed will still push up with the same force because it has to’
- F2 (of electrons repelling): ‘cos they just have to’
- Asked how the poles of a table adjusted the reaction force so the table could support what was on it, F4 replied ‘They just do. I don’t know.’
- M2: the bed doesn’t adjust, or detect, or know, ‘it just does’.
- M11: ‘... [5.9s] ... Maybe it’s not the bed, it’s just like it happens.’

Explanation by decree appeared to be a last resort. It was difficult to avoid. A respondent might have managed to explain everything in terms of the interaction of electrons but still not be able to explain why electrons behaved as they did. When respondents were stuck they might resort to explanation by decree. This was particularly evident when they were trying to explain how a bed could, as M11 put it, ‘Kind of know without actually knowing’ how heavy the object on it was. For example, M2 stated ‘it doesn’t adjust its reaction it just happens’ but he clearly felt that this

explanation was inadequate even to rate as an explanation because he continued by citing and labelling Newton's Laws and later by saying: 'I'm sure there is an explanation, I'm not saying there's not. I just ... I, I'm not, I don't know' and later 'I'm not sure why but I just know that ... it does'.

5.2.2: 'Otherwise'

Sometimes when answering a physics problem it is easier to answer the opposite. For example, when explaining why beta radiation is used to measure the thickness of paper a useful strategy is to explain why the alternatives (alpha and gamma radiation) are not possible. Similarly, some respondents tried to explain why the forces were balanced by explaining why the alternative, the forces being imbalanced, led to consequences that were either ridiculous or just did not happen. Thus:

- F2 knows that the reaction force from the bed cannot be greater than the weight of the dog because 'otherwise the thing ... would be in the air', the dog would levitate.
- M3 laughs when he says that if there is not an equal and opposite reaction supplied by the bed, the dog 'will just ... go through it'.
- F2: 'it push, it has to push up ... otherwise, cause that's just ... how electrons work'; in this example the 'otherwise' looks like the starting fragment of an unfinished thought which is then overwritten by the explanation by decree.
- M5: 'the bed has ... a maximum amount of force acting go back otherwise if you put ... more, if you put above that it's just going to break'
- M5: 'it wouldn't put any more weight ... any more force ... than what's on it otherwise it's just going to ... you know ... send the thing on top of just flying upwards or something and it wouldn't gonna do that'

This type of explanation fits with the use of the ‘Sherlock Holmes’ problem solving strategy.

5.2.3: Describing

The initial response for a number of respondents was to describe. This was initially interpreted as an attempt to avoid the threshold. In physics examinations there is often a distinction made between ‘describe’ and ‘explain’ and a candidate who describes rather than explains is penalised. It was theorised that these respondents might be using a deliberate strategy of giving an answer that they knew rather than speculating about something they did not know (perhaps as a way of establishing a benchmark for their later explanations). However, most of the respondents (M1, M4, M8, M16) who described rather than explained appeared not to be happy with their response and sought to find a better explanation. Therefore they did not appear to be attempting to avoid the threshold. Furthermore, F2 had already shown signs of having entered liminality (‘... [10.4s] ... Hmm ... [6.4s] ... That’s really weird ... [3.9s]’) and M15’s response was so detailed that he may have been unaware that he had not really explained the problem; it seems unjustified to suggest such a response as threshold avoidance. Only M13 did not appear to have seen the threshold. Describing was therefore reclassified as a variety of explanation.

These four respondents sought a better explanation:

- M1: ‘When something of 100 newtons lies on it, it is going to have a reaction force of 100 newtons too ... [1.8s] ... when there's nothing on it, it will have ... zero reaction force ... umm ... [2.4s] ...’ Later M1 made it clear that he was

well aware of the key problem with this challenge: ‘how it adjusts it’s not like it is physically doing it ... because it is ... not alive like the ... weight pushing down.’

- M4 followed ‘So. It’s always balanced ... the weight of the ... thing lying on it ...’ with ‘... [3s] ... No idea but ... Umm ... [2.3s] ... Don’t know that one.’
- M8 stated what happens but immediately paused and sought a cause: ‘OK, so it’s adjusting its reaction force so it will change from ten to five newtons ... uhhh .... [5.9s] ... So in order ... if the force is ... if the force is changing ... [2.6s] ... therefore ... well the normal force is caused by ... it’s like a molecular ... [inaudible] force is [inaudible] the molecules and ... whatever the molecules come in contact with, I believe’.
- M16 starts confidently: ‘Well, every force has an equal and opposite reaction in the opposite ... direction ... of the same type.’ but then restates the problem in a whisper; this suggests that he is aware that his answer is inadequate.

These three respondents did not seem to perceive any inadequacy in their initial ‘describe’ explanation:

- F2: ‘I guess ... it changes because ... [4.2s] ... Unless ... it breaks ... [1.2s] ... They will always be equal’.
- M15: ‘So if object A exerts a force on object B, object B will exert a force ... on object A that is equal in magnitudes, opposite in direction and ... errr on two different objects ... errr it looks to be on the same type of force. So we can assume that the dog is object A and the bed is object B so the dog is pushing its force down on the bed, so the bed will equally push a force up on to the dog to counter it’.

- M13: ‘So whatever the object’s weight is ... the bed exerts a force ... equal and opposite to the object ... so it’s ... always counters ... no matter what it is, within its limits’

5.2.4: Labelling

Labelling is when something is given a name. In science a name is often shorthand for a set of coherent ideas. But if a physicist explained the ‘dog on the bed’ challenge by saying that the forces are ‘in equilibrium’ they would be likely to mean more by the label than the physics learner would.

- M1: ‘because it is in equilibrium’
- M5: ‘that’s Newton’s First Law, is it the First Law? might be third?’
- M16: ‘Just cause ... Newton’s Law’
- M17: ‘Because ... Newton’s Third Law’
- M13: ‘it’s in equilibrium so there’s no net force’
- F4: ‘By reaction force’

M1 clearly felt that labelling was not an explanation because having used it he subsided into stuckness: ‘it’s going to push because it is in equilibrium ... stationary ... so ... [5.5s] ... I don’t know.’

5.2.5: Explanation by intention

It was common for participants to use words and phrases such as ‘wants’ or ‘tries to’ that suggested that non-living entities could have an intention. I have italicised key words in the following transcripts to add emphasis.

- F2 claimed that electrons ‘just *want* to be in a state where their atom, just being an atom.’
- F2: ‘it *wants* to back to where it originally was’
- M2, long after rejecting the words ‘adjust’, ‘detect’ and ‘know’ said that electrons ‘want to be in their shells’ though when challenged he removed intentionality by using alternative formats such as ‘the *ideal* position for an electron’ and ‘the point at which ... [2.9s] ... they’re stable’. This could be considered a move back to explanation by labelling.
- M5 ascribed intentionality to the bed: ‘it’s not going to *want* ... the dog to fall through or it would *want* to balance it out ... the bed doesn’t *want* to push back on it any more than it has to ... it wouldn’t *want* to have to put up any more force going upwards’
- M5 also talked about trying: the surface *‘tries* to ... balance it out’; ‘it’s just *trying* to equal it out’; ‘it *wants* to push back an equal force to what you’re pushing down with’
- M8: ‘the surface of the bed *wants* to be ... flat’
- M12, even after being able to explain how the bed balanced the forces because springs reacted with a force appropriate to that with which they had been compressed, explained how the springs worked by saying ‘they’re *trying*

to return to umm ... their normal state' and 'they're *trying* to expand ... back into their ... original state.'

F2 said, of electrons, 'they have to push up; they have no *choice* but to repel'; this seems to imply explanation by intention.

Although this was not a formal observation, while I attended physics lessons with the participants in order to establish the context of the questions it was noticed that it was not unusual for the teacher to use explanation by intention when talking about inanimate objects.

I classified this as explanation by intention. This is common in explaining human actions by appealing to the intentions of the participants. However, all participants realised that the use of explanation by intention when talking about a surface is problematic:

- M1 denied that the bed could respond 'because it is ... not alive'
- F4 said that the poles of a table couldn't know how hard someone was pressing on the table because 'they don't think'
- M2 claimed 'I don't think the bed knows' and 'it doesn't know it ... just does'.
- M3 stated 'there's no way for it [the bed] to know ... because the bed's not a conscious being' and also 'Because the bed's not a conscious being ... so it's unable to ... <u>know</u>' [know emphasised]
- M5 asserted 'obviously it [the bed] doesn't know, it's not like it's got a brain.'
- M13 said 'it's not a ... living object ... it doesn't know what's on it
- F2 realised that electrons 'have no choice but to repel'

- M11 distinguished between knowing and obeying: ‘Well, it doesn’t know it because it’s a bed, it can’t know stuff, but it obeys ... the law.’ Later he concluded that the bed ‘must in a way kind of know without actually knowing’.
- M12 said the bed couldn’t know how heavy the dog was because ‘It’s an object. It ... doesn’t ... know things ... [4.4s] ... It’s not like a computer it kind of runs on ... data rather than ... knowing things.’ Later he agreed that ‘I guess you could say that’ the bed could measure the weight of the thing lying on it but ‘it wouldn’t know what to do with ... it wouldn’t know that that’s ... you know ... information ... it would be ... just a calculation’. It would seem that for M12 ‘knowing’ meant rather more than having or being able to process information. M13 denied that the bed could ‘tell what’s on it. ... It just knows ... it doesn’t know anything it’s just what .... pushing back the force which is exerted on it.’ He later explained that ‘Cause it’s not a ... living object ... it doesn’t know what’s on it’.
- M14 explained this as ‘I’m going to say that it’s not aware ... that I’m pushing against it ... cause it’s not alive, it can’t ... it doesn’t have sentience and ... it’s not aware of its own existence so it it’s not aware of its own existence how can it be aware of ... something else existing?’

This dissatisfaction with explanation by intention seemed, for most respondents, to be a major cause of the cognitive dissonance that seemed to be responsible for their experience of liminality. Inanimate objects frequently have intentions in stories involving magic such as fairy tales or cartoon films (for example, the talking tree in the *Wizard of Oz*, the talking cars in *Cars*) and even ‘adult’ art (for example, the *Nutcracker* ballet); such animism is therefore part of the culture in which my

respondents grew up. Nevertheless, and despite their teacher using such explanations the respondents seemed aware that these explanations were somehow unacceptable in physics. For example:

- When m9 was asked whether a table could know the weight of a hand resting on it he replied 'No. ... You've really got me now. Umm ... The table knows. ... Because the reaction force always has to equal your hand ... though ... it's ... Yeah I guess the table knows. It's not the table knowing. It's still pushing back at you because you're pushing on it.'
- M2: 'See, it can't detect it, it's, it's not got anything to process ... detecting it's ... it can't adjust either it ... [3s] ... it reacts'
- In a sudden rush of thought which contrasted with his previous hesitant style, m14 stated 'It depends on what you mean by 'know'. The more, the more you say, does it 'know', the ... you relate 'know' to ... knowledge of one's own ... existence but that's sentience. It's used what, it's what you mean by 'know'. So if you say, if you say the bed 'knows' ... something, it depends on what you means by 'know', do you mean is it ... is it conscious that you're pushing against it or do you mean is it ... is it just ... does it just .... push against it.'

Some respondents made interesting epistemological distinctions. For example, M2 felt that the key distinction was that an inanimate object could not choose what to do but it could obey: 'The bed doesn't have any brain or thoughts ... so it doesn't do it ... because it chooses to ... it does it because it has to' and later 'the way that we're describing it, it's like it's ... it's choosing to do what it does ... But it's not, it's just abiding by the laws of Physics'. M5 also made a distinction between 'knowing' what to do and obeying a law: the bed was just 'abiding by Newton's Third Law.

Challenged on this use of language M12 smiled and laughed while explaining ‘it doesn’t want ... it’s just a term of ... describing it ...’

5.2.6: Explanation by design

It could be argued that explanation by design is a version of explanation by intention where the purposive behaviour is removed to a designer: something does something because it was designed that way.

- M6 stated that ‘when a dog pushes down on it the springs ... they’re gonna push back up, ‘cause that’s just how they are made.’
- M5 stated that ‘a surface is something there to stop people falling through due to gravity’

M5 also suggested that a floor ‘wouldn’t bounce back like a spring would ... because that’s not how it’s designed to act.’ although he seemed to find this explanation inadequate because a few seconds later he confessed: ‘I don’t know’.

M6 also offered an explanation by design that had an ‘otherwise’ flavour: ‘If they didn’t push back with that force ... you would just go ... right through them and then ... you would always be ... well ... nothing would ever ... work’

5.2.7: Teleological explanations

A teleological explanation is the idea that something happens in order to achieve an endpoint. An explanation by intention is teleological in the sense that the end is ‘desired’ by the object; an explanation by design is teleological because the end is

that specified by the designer. To give an example from Aristotelian physics, a stone is made of earth and earth's natural place is towards the centre of the universe; by falling the stone is fulfilling its destiny. An erroneous view of Darwinian evolution is as progression towards humanity.

- M5 'to balance it out to stop the bed from breaking it's got to push back'
- M5: also suggested that 'it'll push back on it an equal force ... to stop it from moving ... and then balance'
- M2 suggested that electrons move 'to keep ... their position.'
- M13: 'So [that] it's in equilibrium, not moving'.
- M1: 'whatever is going to push up is five newtons too ... [1.2s] ... to cancel it ...'
- M15: 'the bed will have to push up less on it to counteract its gravity'

Some teleological explanations are not so that something can happen but so that something else does not happen (an 'otherwise' version of teleology, as it were). A number of respondents implied that the forces had to be balanced in order to prevent something happening, either because it was undesirable (for example the bed breaking) or because it was unobserved (for example the meerkat levitating).

- M5 suggested that a surface 'needs something there ... to stop you from falling through'.
- M12 suggested that the forces when you lie on a bed are balanced because 'if the spring didn't give that force back you'd fall straight through the bed'; this was after having given a coherent material explanation of how the springs provided a balanced reaction force.

- F2: ‘Because if it didn’t ... however ... it would sort of just merge together and that’s not how the world works’

These types of explanations could arise from the problem solving strategy of ‘eliminate the impossible’.

M12 preferred the teleological explanation to a material explanation involving springs: ‘the forces have to cancel each other out ... otherwise ... you’re ... going to move and so ... if I sss, if I sit still ... and I have a weight ... then the chair must be pushing back on me to keep me still. I think that’s a much better way of describing it’.

5.2.8: Formal explanation

In the ‘dog on the bed’ problem a number of respondents began by invoking Newton’s Third Law of Motion (this was also classified as ‘labelling’ when the Law was mentioned by name) but many felt that this was an inadequate response.

- F2: ‘it’s just um Newton’s Law ... I don’t know how it works.’
- F2: ‘Force equals mass times acceleration but that doesn’t really help in the situation I guess’
- M2: ‘Every action has an equal and opposite reaction ... I doh, I don’t know why.’
- M1: ‘The reaction force changes ... [1.5s] ... due to Newton’s Third Law ... so .... [9.2s] ...’; M1 doesn’t actually state that he is uncertain but the long pause after the statement allows us to infer his concern that his response might not have been complete. It is more normal for an evaluative pause to last less than four second.

- M3 started by citing the Third Law and repeated this several times.
- M5 also appeals to this law: ‘The rule is that... there’s always going to be an equal and opposite force dependent on what’s on it ‘
- M9: ‘Every force has an equal and opposite reaction’.
- M13: ‘It’s just equal and opposite, isn’t it? Don’t know why.’
- M16 launches straight into ‘Well, every force has an equal and opposite reaction in the opposite ... direction ... of the same type’ but immediately follows this statement with ‘Ummm’ and then repeats the third stimulus for the second time, this time in a whisper.
- M17 was an anomaly, quoting Newton’s Third Law after speculating about the role of the springs.
- M15: ‘It’s according to Newton’s ... Third Law that every action has an equal and opposite reaction.’
- The way that M4 phrased it was as if the formal explanation itself provided a force: ‘Is it ... Newton’s First Law pushing up. Every action has an equal and opposite reaction’. He followed this statement with ‘but I don’t know how’.

M8 is very keen on a formal explanation; he said afterwards that he tended to seek mathematical explanations. For this problem he used Newton’s Second Law (often paraphrased as force equals mass times acceleration) and reasoned that if the mass stays the same and the force required to balance the object changes then the acceleration needed to change.

Some elaborated why they felt a formal explanation was not adequate:

- M2 felt that there was a problem with citing the law as an explanation. ‘It’s the law of physics ... the bed doesn’t have any ... brain or thoughts ... so it doesn’t do it ... because it chooses to ... it does it because it has to’ again reinforcing the idea that intentionality is somehow permissible as long as it doesn’t involve choice.
- M15 pinpointed the problem. ‘The bench won’t like know Newton’s Third Law and be like oh that’s Newton’s Third Law I’ll follow this it just is like ... Newton’s Third Law is what we as humans use to explain ... what’s happening here.’ His position therefore acts as a rebuttal to M2 and M5 who suggested that a bed would ‘abide’ by Newton’s Third Law.

5.2.9: Saving the phenomena explanations

These are explanations in which a theoretical entity is hypothesised. Moliere lampoons the medicine of his time in *The Hypochondriac* when he refers to opium inducing sleep because it contains a dormitive principle; he is suggesting that such an explanation is tautologous. However there are examples of ‘saving the phenomenon’ explanations throughout the history of science, such as the epicycles of Ptolemaic astronomy and Lavoisier’s caloric, the substance of heat (and its reverse frigoric) and one could regard current concepts such as gravity to be theoretical entities hypothesised in order to explain why things fall.

- When M1 says: ‘the spring isn't collapsing upon itself it’s going to push up because of the quality of the spring ...’ he seems to be employing a ‘saving the phenomena’ explanation.
- M1 invents wood particles: ‘they’re not springs but there's loads of ... errrr ... [1.9s] ... small ... [2.4s] ... structures ... [1s] ... that are wooden ... that are

whatever the woods made of together ... So ... [2.5s] ... OK ok so if the floors made out of wood there's loads of ... [1.1s] ... I don't know what wood's made out of wood, it's like, wood, innit ... But ... [1s] ... compare to the springs whatever the little structures are there keeping the wood ... [1.1s] ... particles together'

5.2.10: Material explanations

Material explanations provide a causal mechanism.

- M1: 'when you put more pressure down on the spring ... the spring has got to push up ... more.'
- M5, when asked if there is anything in the bed that might help solve the problem realises that the bed has springs and swiftly concludes 'if they've got less weight on top of them they're going to be compressed less ... so with the meerkat they will be compressed less than when the dog is on it'
- M11: 'if there's more weight on it, it squishes further'
- M12: 'I will sit down and the force will be ... you know ... the force will be greater than ... you know ... the force will be greater than ... what the chair is exerting upwards ... and .... as I ... compress down ... the chair's force will ... start to rise and exceed my .... and then push me back up ... and it will ... reach an equilibrium.'
- M13: 'The springs push a force back because that's the energy they've gained from being compressed.'
- M15: 'if it is like a really light object the springs will be like less dense and ... less compressed, I guess ... so err it will have to push up less.'

- M17: ‘as the weight is increased the compression of the springs increases which exerts a larger force against ...’
- F2: ‘You’ve got a dog and his electrons ... are there ... and then the spring's electrons are there, they’re sort of ... repelling one another which is why it pushes up’

On the whole respondents seemed satisfied with material explanations. Although there were some who worried that, for example, explaining how the bed provides a reaction force through the compression of its springs simply shifts the question to ‘why is that when you squash a spring more it pushes back harder?’ It was at this point that some respondents reverted to a teleological explanation or an explanation by decree.

5.2.11: Explanations within limits

There was a particular fondness for explanations within limits; some of the respondents seemed obsessed by catastrophe such as the bed breaking:

- M1 discusses a spring being compressed ‘until a certain point where it's ... squashed completely’; when he discusses weights on a floor he states that ‘the floor doesn't dip until ... the weight gets really big and the floor's going to crack’.
- When I asked M2 what happened in the Young Modulus experiment they had recently performed when more weight was added to the wire (it stretched more) they answer was ‘It stretched it out. It went past its elastic region into its plastic regions’.

- M3 too, prompted to think about the experiment with springs , was interested in ‘the point where it ... stretches too far’ and emphasised that ‘there’s ... only a certain amount of force that the bed can push back with’.
- M5 develops a hypothesis: ‘the bed has a maximum amount of force acting go back otherwise if you put ... more, if you put above that it's just going to break.’
- F2 is also concerned with limiting cases, talking of the elastic limit of the springs, the body ripping through the bed, things being ‘too heavy’ and, after a certain point, the bed breaking.
- M13 was concerned that ‘If the force gets too big the bed will just break because it can’t push back.’
- M15 ‘The table just has a maximum capacity ... that it can hold against. If I exceed that capacity it will break’; he agreed with my suggestion that ‘we deal with things within their limits.’
- M8: ‘my weight is ... greater than so it ... overcomes ... whatever sort of threshold ... the, the springs within the mattress have to ... stay ... uncompressed’.
- F4: ‘The springs compress in the mattress to ... make sure that the dog doesn’t ... go through the floor.’

In some ways this concern with catastrophe linked to an explanation by design as if a designer had included obedience to Newton’s Third Law as one of the properties of the bed so that it would not break.

5.3: Strategies

The transcripts suggested that respondents used a number of strategies to cope with liminality. It was clear that some respondents used some strategies consciously and deliberately; other ‘strategies’ may have been applied subconsciously and may be not so much deliberative strategies as innate ways that a learner experiencing liminality copes.

Some of these strategies were used early in the response and others later:

- Some strategies associated with the threshold itself:
    - Restate the problem
    - Call to action
    - Denial
    - Swift surrender
- Some strategies were associated with passing through the liminal experience:
    - Call to action
    - The Edison
    - Exploratory thought
    - The White Queen
    - The Sherlock Holmes: eliminate the impossible
    - Using analogies
    - Frame by Frame

5.3.1: Restate the problem

Many respondents started their response by repeating or restating the problem. They often modified the stimulus using principally three techniques:

- Selection of key parts of the stimulus
- Emphasis through hesitation
- Whispering or muttering.

Some respondents used a combination of these.

For example, M1 restated part of an experimenter stimulus in a whisper: ‘standing on a floor ok ... so ... [2.4s] ...’ The selection of a part of what I had said could be interpreted as M1 strategically focusing his attention on what he considered to be important. The whisper suggests that he was using reflective self-dialogue to help him think about the problem. The ‘Ok ... so ...’ could be interpreted as thought initiation although given that M1 seemed to enter into boggy ground stuckness an alternative interpretation might be that M1 was attempting to initiate a thought using these words.

For example:

- M17: ‘The weight of one hundred newtons. What forces act on him when he lies on the bed?’
- M17: ‘The dog jumps off the bed and is replaced with a five newton meerkat. What forces [laughs] act on the meerkat? ... Jumps off the bed ...’
- M17: ‘How does the bed adjust its reaction force so that it always balances the weight of the thing lying on it? ... [10.5s] ... Balance the ...’

- M1: ‘How does the bed adjust its reaction force so that it always balances the weight of the thing lying on it? ... How does the bed adjust its reaction force?’
- M16: ‘How does the bed adjust its reaction force so that it always balances the weight of the thing lying on it? How does the bed ... adjust its reaction force ... so that it always balances ... the weight ... of the thing ... lying on it?’
- M4 repeated key words, combining selection with hesitation: ‘Bed adjusts ... balance ... the weight ... [4.6s] ... How does the bed adjust its reaction force? ... So. It’s always balanced ... the weight of the ... thing lying on it’
- M1: ‘So the dog is gonna be pushing up on the bed ... [whispers] the bed’s gonna be pushing up on the dog. ... yeah ... uhhh ... [4.9s]’
- M2 read at least part of the second stimulus silently but when he started to read aloud he used hesitations to isolate what, one presumes, he considered to be the key information, the weight of the meerkat: ‘... and is replaced with a ... five newton ... meerkat.’
- M3 read aloud, using hesitations to chunk the text: ‘How does the bed adjust its reaction force ... so that it is always ... balances ... the weight of the thing lying on it.’
- M12 read selected words from the second stimulus in a whisper as if he were engaging in reflective self-dialogue. He also used hesitation to segment the stimulus into semantically meaningful chunks: ‘The dog jumps off the bed ... and is replaced ... with a five newton meerkat.’ He then repeated ‘ What forces act on the meerkat?’ in a mutter and again in a normal voice: ‘ act on the meerkat? Ummm.’

This applies as well when the stimulus is not one of the standard ones (the first, the second or the third stimulus) but an intervention from me. For example:

- When I asked '*Can you apply that idea of a dog on a bed or a meerkat on a bed to standing on a floor?*' M1 selected some of the words and, in a whisper, replied: 'standing on a floor ok ... so ... [2.4s] ...'

When M6 responded he first repeated part of the third stimulus 'How does it adjust the thing'. He missed out the words in between 'adjust' and 'the thing' which are ' so its reaction force is always balanced to the weight of'. He then paused for 1.4s and then said 'balances the weight of the thing lying on it'; he has more or less replaced the missing part. This behaviour is consonant with the idea that where the respondent selects just a part of the stimulus to repeat they repeat the part they feel is most important. It suggests that M6 used the pause to evaluate what he had selected and then decided that the balancing was also important so decided to repeat that as well.

It might be suggested that the purpose of repeating or restating the stimulus is a delaying tactic, a way of postponing entry through the threshold. Alternatively it could be a way to internalise and make sense of the stimulus. For example, whispering and muttering are also indicators of reflective self-dialogue which suggests that the respondents using these techniques are doing so in order to consider stimuli better. When the stimulus is repeated using hesitations it is broken into segments each of which seems semantically coherent; it is fragmented but each fragment makes sense. This is analogous to the way the grounded theory method advises fragmenting texts before reassembling them into categories. Finally, it seems

reasonable to assume that when only certain words are repeated, the selection is important. It is as if the respondents are doing the oral equivalent of highlighting the key words in an exam question. This would mean that for M17 in the first example what is important is the dog jumping off the bed; M17 swiftly uses the 'frame by frame' strategy to solve the problem by identifying the dynamic nature of the change so for M17 the fact that the dog jumped off the bed was indeed one of the keys to his solution. And in the second example M17 focuses on the balancing aspect which is also important to his solution. Meanwhile M1, who takes far longer to solve the challenge, is focussing on how the bed adjusts; this is for him a source of puzzlement: he later goes on to worry 'how it adjusts it's not like it is physically doing it ... because it is ... not alive'. It therefore seems that the words selected to repeat may provide a clue to the way the respondents tackle the challenge.

Having become stuck, M6 started to draw the dog on the bed problem, perhaps as a way of restating the problem in a different form and presumably as a way of breaking the deadlock.

5.3.2: Denial

Some responses to the third stimulus were, on the face of it, to deny the problem. This could be interpreted in two ways: either as an attempt to avoiding the threshold or as an acknowledgement of the key epistemological issue which is that the bed, as an inanimate object, cannot consciously 'adjust' its reaction force.

Most respondents who denied the problem adopted the latter position:

- M2: ‘Right. OK. ... Umm ... I don’t think the bed ...literally adjusts its reaction force’. With his first words M2 seems to acknowledge the challenge. The denial is tempered by the word ‘literally’; he seems to be suggesting that the heart of the problem might lie in the word ‘adjust’.
- Similarly M12’s denial of the problem seems to provide a springboard for explanation rather than an avoidance strategy: ‘I wouldn’t have thought it adjusts a reaction force but ... because the reaction force is always there, it follows the object around’; later he confirms this idea: ‘the bed doesn't adjust its ... the reaction force. ... The reaction force is ... ummm ... pushed back from the bed when the weight is put on it.’ This enables him to see the answer: ‘Or the springs?’
- Like M12, M15 doesn’t deny what happens, just that the adjustment is provided by the bed: ‘ Errr, Well the bed doesn’t do that. It’s according to ... Newton’s ... Third Law that every action has an equal and opposite reaction.’

Even M3, who appears to deny the problem, then has second thoughts: ‘Errr ... The bed doesn’t ... adjust its ... force ... Well ... Ahhh ... [1.4s] ... This ... ahh ... I knew something like this would come.’

5.3.3: Swift surrender

M4 follows a repeat of the question and a restatement with a swift admission of defeat: ‘... [3s] ... No idea but ... umm ... [2.3s] ... Don’t know that one ... [1.3s] ... I think it’s ... yeah ... no ... I dunno ... umm ... [1.4s] ... I’ve got no idea ... [1.8s] ... I think it’s ... [1.6s] ...’. He seems to be surrendering. But he doesn’t. All of this is

immediately preliminary to his uttering a key idea: ‘Cause I ... after what, after time they balance out but instantaneously they’re not ... err ... [2.8s] ... balanced ... ‘cause ... the dog ... is the bed norm ... normally isn’t acting up, pushing up on anything.’ These repetitions suggest that this is a ‘possible breakthrough idea’ and the realisation that there might be a moment when forces don’t balance leads to the next passage in which the fluency is much improved: ‘But then when it all lies on it, the bed push up ... harder up ... to make, so the dog doesn’t fall right the way down and then it will ... eventually balance out like ... bit like drag ... and acceleration ... like when you’re falling the drag is lower and as that increases then it balances ... But it’s a lot quicker ... That’s my answer.’ Not only has he offered an acceptable answer, and he appears to be aware of it, but also he has explained it using an analogy with the experience of a skydiver who, as he falls, accelerates which increases the drag of air resistance which in turn reduces the acceleration so that eventually the force from gravity is balanced by the air resistance, as the force of the dog’s weight is balanced by the reaction force from the bed in our example. His response when I then ask how the bed adjusts is another swift surrender: he pauses 2.6s and then says ‘Don’t know’. This is much closer to refusing the call than before.

5.3.4: Call to action

Reflective self-dialogue sometimes seemed to be used as a call to action. Over the last 37 seconds since M6 read the third stimulus all he has been able to do is pause or repeat parts of the stimulus. He seems to be stuck. He says ‘so’ which is used by many respondents to introduce a thought. M6’s thoughts at this point are not very coherent: ‘... [3.2s] ... By balance it is, is, all it is off, all it’s trying to say is ... [1.6s] ... How it ... [1.4s] ... Keeps it how the force is actually pushing back off of it ... [1.4s] ...’

Now he says ‘OK’, also used by some respondents when initiating thought. He follows with ‘umm ... [5.6s] ...’ Now he says ‘Well’ and pauses for 3.7s before he finally gets going with an attempted solution. This might be explained if M6 was using the words that normally mark the beginning of a thought as a way of jump-starting a thought, as a call to action.

We see this ‘call to action’ in other respondents.

- For some it is the first utterance of the transcript:
    - M5: ‘OK. So ... [2.7s] ... What forces act on him? ...’
    - F2: ‘OK, so ... First I know that it’s concerning forces’
    - M2: ‘so ... [1.3s] ...’
- Sometimes it works. Thoughts start:
    - M1: ‘uhh. OK. OK. ... So ...We already know that ...’
    - M3: ‘so ... [1s] ... yeh, every action has an equal and opposite reaction ...’
    - M5: ‘OK. So ... If you use ... if it’s another meerkat’
    - M5: ‘Right. So. ... [1.9s] ... The rule is that... there’s always going to be an equal and opposite force dependent on what’s on it’
- Sometimes it occurs after a long pause, as if it is being deployed to break the deadlock:
    - M5: ‘... [12.2s] ... I don’t know ... [11.7s] ... Right, so ... [2.5s] ... to balance it out ...’
- Other times it fails:
    - M1: ‘So ... [6.9s] ... [very quietly] I don’t know’

- M1: ‘so umm ... [6.3s] ... I don’t know how to apply that though ... to this’
- M6: ‘Not the this it will just be this point here ... so ... [4.6s] ...’
- M8: ‘you know ... so ... [6.1s] ... I don’t know, maybe it’s ... [4.3s] ...’

- There are times when the words acknowledge that a thought is already on the way:
  - M1: ‘And then then ok so the bed is pushing back on whatever is on it’: the repetition of ‘then’ marks the rush of thought when a ‘possible breakthrough idea’ is arriving.
  - M1: ‘So ok ok ok so that would be ... a push, person is pushing ... downwards so ... [1.8s] ... downwards, say a force of, say the dog, the dog’s pushing downwards with a force of a hundred newtons on the Earth’

M8 uses ‘so’ to introduce sub-thoughts in this extract: ‘So we’ve got the normal ... force ... he’s not moving, so, there’s no friction, involved although it, so, I am right in thinking it only becomes present ... when he’s moving ...’

The thesis here is that words that are associated with thoughts starting, such as ‘OK’ or ‘so’ or ‘well’ are used strategically to try to initiate thoughts when the respondent is stuck.

5.3.5: The Edison

F2 explicitly used a strategy of listing everything she could think of: ‘I’m just trying to think of everything that I know ... concerning forces’ and later ‘I’m just trying to [inaudible] everything I know about electrons’. When she responds to the first ‘dog on the bed’ stimulus she initiates thought using ‘... [2.2s] ... OK, so’; she then orients herself to the situation by stating ‘First I know that it’s concerning forces’; she pauses for 2.1s and then connects the orientation with previous knowledge saying ‘and ... I know an equation’. Still later she implies this strategy: ‘‘All I know ... they’re made up of quarks which is probably irrelevant ... but still it’s a thing’. She seemed to be trying to consider everything she had learnt to see whether she could recognise one that might help her solve the problem. Presumably, she was starting from the optimistic point of view that this was a puzzle she was solving, ie it has a solution, rather than a potentially insoluble problem; that it was possible to discover the truth at least in the artificial context of the task she had been sent. However, she concluded ‘But none of them sort of really help ... Or I’m just not seeing the answer.’ On the other hand, this strategy was used by F2 on her way to a ‘possible breakthrough idea’. She considered one by one the things she knew and didn’t know: ‘I know it’s something to do with electrons ... and how they repel ... [2.6s] ... one another ... and they’re not, I know it’s not really anything to do with Hooke’s Law ... [2.2s] ... And I know pressure because ... it’s how spread out ... the weight is on the springs like if you had a really heavy thing ... on one spring ... that spring would just be taking all the weight ... [2.1s] ... And like the bed will still push up with the same force because it has to ... [2.2s] ... But that’s just more strain on that point ... and if it’s like the dog lying over

springs ... it’s a lot more ... over the springs ... [1.3s] ... So that’s how it adjusts!’ It seemed that in this case the strategy had worked.

This strategy seems similar to the one used by Edison: when inventing, for example, the electric filament lamp and the storage battery he is reported to have tried ‘everything’, systematically searching hundreds of materials and combinations of materials (Dyer and Martin 1998, 599 - 613). Of course, such a method depends on being able to recognise which of many ideas has the potential to lead to the answer. This is like ‘getting warmer’ which I discuss below.

No other respondent adopted an ‘Edison’ approach to the extent that F2 did, at least no other respondent was quite so explicit about doing so. Perhaps when M13 says ‘There has to be some sort of force ... [7s] ... Electromagnetic maybe?’ he has been going through the same process during the silent pause but there is no evidence for the Edison strategy having been used by any other respondents.

Perhaps M8 has been trying to use Edison with (very) limited success when he reports ‘I can only think that the acceleration is changing’

5.3.6: Exploratory thought

Many of the transcripts extracts seemed to show respondents adopting a certain type of thinking. For example:

- M1 says: ‘I don't know ... I don’t know ... I'm thinking that it's whatever’s pushing down on the bed is gonna push back’;
- F2: ‘I guess ... it changes because ... ‘;

- F2: ‘I guess you can think of it as pushing down’
- F2: ‘say if the bed was a magnet’
- M4 laughs and says ‘That’s my answer’;
- M5 uses the phrase ‘my thinking would be that’;
- M8: ‘whatever the molecules come in contact with, I believe’;
- M15: ‘the springs will be like less dense and ... less compressed, I guess ...’;
- M16: ‘there’s springs in the bed, I guess’;
- M17: ‘Will it be to do with the springs?’.
- M8: ‘I don’t know ... I, I’m not sure ... but ... I would say ... probably ... it .... I can only think that the acceleration is changing’

In each of these examples the respondent suggested that they were uncertain of their suggestion (‘I’m thinking’, ‘I guess’, ‘say if’, ‘I believe’) or they acknowledged that this was their own idea, implying that there might be other possibilities (‘my answer’; ‘my thinking’). The key feature of this approach is that the respondents accepted uncertainty; whilst exploring the idea they were able, at least for the moment, to suspend worrying about whether they were right or wrong.

Another version of exploratory thought was adopted by F2 when she deliberately sought to reframe the problem: ’if you think of it in just a different situation ... it might help’.

5.3.7: White Queen Strategy

The extreme position of this was to deliberately explore something that they knew to be incorrect. For example:

- F2: ‘I know this is impossible, but say it’s got fifty electrons’

- F2: ‘electrons don’t work like that’ but ...
- M8: ‘Cause it’s not, it’s not like, it’s not like upthrust when, you know like the boat in the water when the water displaced is, is keeping it, or perhaps it is, it is like that.’
- M8: ‘let, let’s treat the bed like, I don’t know, a fluid [laughs]’.
- M12: ‘I could lie on the ground and there’d be a reaction force of ... one hundred newtons up ... and I could be ... there’d, I could be a force of one hundred newtons down ... well it wouldn’t be but ... I’d have ... the same .... weight ... as the reaction force pushing me up or I’d fall through the floor.’

This strategy reminded me of the White Queen in *Alice through the Looking Glass* who learned to ‘believe in six impossible things before breakfast’. (Carroll, 1963)

5.3.8: Sherlock Holmes: Eliminate the Impossible

An alternative exploration of impossibility is shown by the ‘Sherlock Holmes’ technique. In the ‘dog on the bed’ task, all participants rejected the explanation that the bed somehow measures and reacts consciously to the weight of what is placed on it; as far as the respondents were concerned this was impossible and therefore it was immediately eliminated.

Individual participants also rejected the idea that the dog would weigh more than the bed pushed back up, because the bed did not break, or the opposite idea that the weight of the dog is less than the reaction force from the bed because that would

have the consequence that what was on the bed would be shot up in the air; ‘the meerkat’s go flying’ as m2, laughing, said. For example:

- m3 stated that ‘the equal ... and opposite reaction ... has to be the bed pushing back on the dog to hold it up otherwise it just ... go through it’.
- m5 offered both sides of the coin in separate statements twenty seconds apart: ‘the bed has ... a maximum amount of force acting go back otherwise if you put ... more, if you put above that it’s just going to break’ followed by ‘any more force ... than what’s on it otherwise it’s just going to ... you know ... send the thing on top of just flying upwards or something and it wouldn’t gonna do that.’ Having offered this argument, however, he became stuck: ‘yeah ... I don’t I don’t really know how to ...go about this one’. Nevertheless, he uses this argument again when, having solved the ‘dog on the bed’ problem, he is asked to generalise to a person pushing down on the surface of the bench.
- M8: ‘acceleration’s the only thing that I can think of that would affect ... the force .... because, you know, F equals m a, so, and the mass is constant of the bed and the acceleration and mass, the weight, of the, the meerkat toy ... is constant so therefore the only thing that could change ... is the acceleration due to ... normal force’

It seemed that respondents were using variants on a logical strategy also used by Sherlock Holmes: ‘when you have eliminated the impossible, whatever remains, *however improbable*, must be the truth’ (used several times in the stories but this example taken from *The Sign of the Four*, chapter 6, Conan Doyle 1989, 122) .

- m6 is asked by me ‘How does it know how much to push back?’ and replies ‘if it didn’t push back with that much force the dog would move down so ... it knows ... as soon as it ... reaches ... the point where the dog isn’t float ... it’s reached the point where ... the dog’s just still ... and so ... that’s the right amount of force’. He also stated that ‘If they didn’t push back with that force ... you would just go ... right through them and then ... you would always be ... well ... nothing would ever ... work’; linking the problem-solving strategy of eliminating the impossible with explanation by design.
- f2 also used this argument when she suggested that ‘Unless ... it breaks ... they will always be equal’ and ‘‘cos it can’t be pushing up with a hundred and fifty newtons ... say all the time ... otherwise the thing ... would be in the air’
- m1 suggests that if the object on the bed was very heavy then the bed ‘would probably crack a little bit’
- m5 suggests that ‘if you put, like ... I don't know a thousand tonnes on it or something it wouldn't be able to hold that much weight. The bed would break.’
- M8 also realised: ‘Cause it’s not going through the bed and it’s, and the bed’s not, it’s not ... rising ... so’.
- M8 also used ‘eliminate the impossible’ to focus on acceleration: ‘F equals m a so, and the mass is constant of the bed and the acceleration and mass, the weight, of the, the meerkat toy ... is constant so therefore the only thing that could change ... is the acceleration ‘ Subsequently he claimed he used ‘process of deduction’ to conclude that ‘it must be acceleration because, you know, if ... the mass of the dog, the acceleration due to gravity on the dog and the mass of bed, if that’s the same, then it must be this acceleration’.

- M12: ‘I’d have ... the same .... weight ... as the reaction force pushing me up or I’d fall through the floor.’

5.3.9: Using analogies

A less transgressive approach is to use an analogy. The obvious analogy in the ‘dog on the bed’ challenge is between the dog on the bed of the first stimulus and the meerkat on the bed of the second stimulus:

- M1: ‘They’ll be exactly the same, just ... with a different magnitude’;
- M8: ‘it’s just the same but with different numbers basically’;
- M2: ‘That’s the same’ and later ‘kind of exactly the same’.
- M4: ‘It’s the same forces but just ... different ... size force’
- M5: ‘Same situation’
- M6: ‘Would not be the same? ... just’
- M13: ‘It’s the same but with ... five newtons’
- M15: ‘it would be the same forces’
- M16: ‘Exactly the same thing’

It is interesting to note that ‘exactly the same’ and ‘the same’ did not mean ‘identical’ but ‘similar’.

Other analogies were used when trying to explain the third stimulus and when trying to generalise from the dog on the bed, once that had been understood, to people of different weights standing on a floor, or someone pushing down on a bench or a table with different forces. For example:

- M1 suggested that since the bed contained springs, the wooden floor might contain ‘not springs but ... loads of ... err ... small ... structures ... that are wooden’; his analogy was on a concrete basis rather than at the level of the principle of springiness.
- M1 also recognised a potential analogy between the compression in the springs of the bed and when a spring is ‘stretching ... which is kind of the same thing’.
- F2 compared atoms repelling to ‘when you try and push two magnets together ... except on a smaller scale’
- M8 is laughing as he suggests ‘let’s treat the bed like, I don’t know, a fluid’; he later oscillated in and out of this analogy: ‘Cause it’s not, it’s not like, it’s not like upthrust when, you know like the boat in the water when the water displaced is, is keeping it, or perhaps it is, it is like that.’
- F4 made an analogy between the dog on the bed and a person standing on the earth: ‘The earth is like the spring pushing back up on it.’ She also said: ‘They’re the same situation, just on a different scale.’
- M2 compared the ‘dog on the bed’ to an experiment he had experienced involving using weights to stretch springs: ‘I suppose the ... the weight’s a lot like the dog’ and later ‘the bed which is the ... [1.8s] ... wire’.
- M4 developed an analogy between a dog on a bed and a skydiver falling through the air to solve the challenge.
- M8 also used this analogy: ‘it’s kind of like terminal velocity’
- M6 made an analogy between a person using sufficient force to stop something they wanted to stop and the floor providing a reaction force to balance the weight on it (‘so it’s the same with the floor’) but as he progressed

he realised the limitations of the analogy (‘it’s kind of) and started to withdraw from it (‘the floor automatically does it though’).

Some respondents were wary of the limitations of analogies:

- F2 worried ‘I don’t know that atoms behave quite like springs’
- F2: ‘electrons don’t work like that it’s like that but it’s pushing up with the same ... like they’re repelling at the same’
- M15: ‘a rubber band would have a larger elastic limit than this bench but everything will have an elastic and plastic limit so I guess you could say it’s similar to a spring but ... not very’

Some respondents were hostile to analogies:

- M1: ‘obviously there's no springs in a floor’; this meant he ended up stuck: ‘to be honest I don't really understand ... Newton's Third Law’. Later on he insisted that ‘Nothing actu, gets compressed’ and repeated that ‘there's no springs in the floor’ and that ‘wooden floorboards for a house they’re not going to be made out of springs’. He maintains this hostility to analogy even after inventing new structures in floors than can act like springs: ‘in the floor ... [1.5s] ... essentially there’ll be loads of small ones ... they’re not springs but there's loads of ... errrr ... [1.9s] ... small ... [2.4s] ... structures ... [1s] ... that are wooden ... that are whatever the woods made of’
- M4 wouldn’t compare an experiment in class on springs with the springs in the bed mattress for two reasons. First ‘that was the other way: pulling it instead of ... compressing’ and secondly because in the experiment they have

stretched the springs so far that ‘when it got to a certain point it wouldn’t go back to its norm, original size ... [2.3s] ... so this doesn’t apply.’

- M4 was even more unable to apply what he had discovered to the floor ‘‘cause the floor’s made of concrete, it doesn’t push up ... well it does but it doesn’t’ Because he did not see the analogy he was unable to generalise what he agreed he had learned about the ‘dog on the bed’ to the problem of how the floor pushes up with the correct reaction force.

5.3.10: Frame by Frame

When m17 was given S#8 he paused for just over eleven seconds and then asked himself: ‘Will it be to do with the springs?’ After another pause of slightly over two seconds he started to give the answer, paused again, then said ‘oh right ... right ... I’ve got it’ and continued with one of the swiftest and most coherent answers observed. At the end of the interview he was asked about how he reached his answer. He started by ‘kind of setting up the scenario in my head ... what ... and like thinking about ... eliminating everything that happens so the dog gets on the bed, the bed starts to weigh downs and then ... I got to the point where the springs compressed and so I was like ... right if the springs compress there must be a higher pressure and a higher force ... going back to its ... original position.’ In other words he seems to have set up the situation and then played a film in his head frame by frame or step by step, a very successful strategy for solving this problem.

M12 is not explicit about the strategy he uses but when he explained how he solved the ‘dog on the bed’ problem he said ‘when you get into detail about thinking how the spring compresses and then decompresses as you get on to the bed and as you get

off the bed it's ... almost weighing out ... and then eventually reaches the kind of it equal'. He accompanied this explanation with hand gestures that mimicked the bed squashing and a set of scales. This evidence suggests that he too was 'seeing' the dynamic aspects of the situation as if it were a movie being played; he too seemed to be using the 'frame by frame' strategy. Intriguingly, M12 retranslated his ideas into the first or second person, talking about 'when I get on to the bed' and 'when you lie on the bed'.

F4 also described the third stimulus as if she was watching it happening: 'when the dog ... jumps off, there ... there's no gravity downwards 'cause there's no object on the bed, and then there's also no ... upwards resistance and then there's no force and then the meerkat is ... replaced with the dog ... and then ... the bed adjusts with its springs?'

M1 also hints at seeing what happens: 'So because whatever is on it has a weight pushing ... a force pushing in to the bed ... it ... literally pushes the bed downwards'.

One of F2's 'possible breakthrough ideas' also seems to have come from a frame by frame analysis when, following a dialogue with me, she says 'it's the spring sort of ...uncoiling and getting back to its original shape that pushes up on the meerkat'

5.4: Describing Liminality

In this study the liminal experience was elicited in a number of respondents using a cognitive challenge. In order to solve the problem posed the respondents had to find

an appropriate explanation. The transcripts suggested that some explanations were preferred to others and that a major part of the challenge experienced by the respondents was to achieve an explanation at an acceptable level.

In order to find such an explanation the respondents engaged in problem solving strategies. A number of such strategies were described. The more successful of these strategies used some sort of imaginative technique such as the imagining the impossible or a role playing visualisation.

Some of the characteristics to the liminal experience were common to a number of respondents. Two types of stuckness (brick wall and boggy ground) were observed. Almost every respondent was observed to use reflective self-dialogue. Many respondents experienced a breakthrough realisation such as a moment of truth or a ‘possible breakthrough idea’ but one of the difficulties experienced by many respondents was an inability to assess the potential of an idea.

This description of liminality emerged from the microanalysis of the transcripts using the grounded theory method. In the next chapter I shall discuss these characteristics with reference to ideas already established from the literature review. Where concepts were previously unheralded, such as the idea of reflective self-dialogue or the difficulty experienced in assessing potential of ideas, the discussion will employ a second literature review.

Chapter 6: Discussion and Second Literature Review

The empirical stage of this study has uncovered a number of characteristics of the liminal experience. Liminality was initiated through a cognitive challenge involving a mismatch between the explanation the respondent felt they needed to supply and that they could supply. In order to resolve this they used a number of problem-solving strategies. Characteristics of the liminal experience included two types of stuckness and the use of reflective self-dialogue. Many respondents experienced a breakthrough in their thinking in the form of a 'possible breakthrough idea'. One of the problems that respondents encountered was evaluating the potential of their ideas so they could decide whether they were worth pursuing or not.

The findings of educational research are often highly context-dependent. The findings above may only apply to the highly specific situation of this study. In order to assess their generalisability it is necessary to revisit the existing literature. Since a number of the characteristics (reflective self-dialogue, the issue of potential, the importance of explanation, aspects of the 'possible breakthrough ideas') had not been presaged by the literature on threshold concepts the second literature review will be directed towards these areas.

In this chapter each of the empirical findings shall be considered in the light of the literature. Some of the categories that were expected but for which little or no evidence was found (threshold avoidance and oscillation) shall also be considered.

The aim is to develop a description of the liminal experience which has the potential to be generalised outside the immediate context.

6.1: Cognitive challenges and explanations

The purpose of this study was to evoke a liminal experience in respondents and observe them. The stimulus chosen referred to an aspect of Newton's Laws of Motion; Meyer and Land (2003, 7) linked these to troublesomeness; this provokes liminality (Land *et al.* (2010, xi) and instigates new learning (Land and Meyer 2010, 63). It was therefore expected that the stimulus would provoke liminality.

But this does not fit the response of, for example, M1 which can now be analysed using the codes that have been developed in the last chapter. M1's first reaction had been to read aloud the stimulus ('How does the bed adjust its reaction force so that it always balances the weight of the thing lying on it?') is to restate part of it in a whisper; the analysis developed suggests that he is using reflective self-dialogue to analyse the challenge. But he then continues to describe what happens.

There are alternative interpretations of this behaviour. One interpretation is that he has perceived the threshold and decided to avoid it. Another interpretation is that he has misperceived the threshold, he has misunderstood the challenge, perhaps because the previous questions led him to expect a standard physics question which asks what happens rather than how it happens. But his whispered restatement of

part of the stimulus makes it unlikely that he has misunderstood what the stimulus requires.

A third interpretation is that M1 has fully understood the challenge and believes that his response is adequate. If this is the case such belief is transient. Having offered his first response he enters a period of boggy ground stuckness: he pauses, articulates an idea, pauses again, and articulates another idea in three sections, pausing in between each section.

At this point I intervened to focus again on the stimulus: ‘How does the bed adjust its reaction force?’ Again he responds with a typical example of boggy ground stuckness. A pause is followed by a ‘possible breakthrough idea’ which is itself followed by a pause during which there is a failed attempt at thought initiation. Now M1 describes what happens again and pauses before saying ‘I don't know ... I don’t know’. Another idea follows this and is itself followed by a moment of truth: ‘it's not like it is physically doing it ... because it is ... not alive like the ... weight pushing down’. Finally yet another description of what happens is followed by a further pause.

This cannot be interpreted as threshold avoidance: the boggy ground stuckness that M1 is exhibiting shows that he is experiencing liminality. Nor can it be suggested that M1 has failed to perceive the threshold: the moment of truth articulates the challenge. But it articulates the challenge as M1 sees it. He has realised that he could explain what is happening if the bed were alive. The cognitive challenge stems

not from his inability to explain what is happening but from his inability to explain using an explanation that he deems acceptable.

Such an interpretation encapsulates the principle that the experience of liminality must be viewed from the perspective of the learner. As Meyer and Land (2005, 384) point out, we must consider how the threshold comes into view; as Ausubel and Robinson (1969, 124) assert, what is learned is not the same as what is taught.

6.1.1: Avoiding the threshold

The literature review found that many theorists argue that one reaction to a cognitive challenge is ‘an active refusal of learning’ (Meyer and Land 2006b, 30). The reasons suggested are that the learner may be overly anxious (Bao *et al.* 2013), calculate that the cost of learning is too high (Atherton 2013), feel threatened (Lee *et al.* 2003, 587 - 590; Mezirow 1990a, 4), or be insufficiently resilient (Zohar and Aharon-Kravetsky 2005). Savin-Baden (2006, 164 - 165) suggests that respondents may seek to find an alternative route that avoids the threshold; she lists five alternatives (Savin-Baden 2008, 81): retreating from the threshold, postponing dealing with it, procrastinating, temporizing and avoiding it. Concept change learning theorists (for example, Bell 2005, 63) point out that a constructivist position implies that, since pre-knowledge is used to interpret new information, a learner may fail to see the challenge. In other words, the failure to pass through the portal into liminality always seems to be ascribed to a deficit on the part of the learner.

The evidence from this study failed to support threshold avoidance. It has been shown above in section 5.1.4 that evidence which might be interpreted as prevarication such as long pauses or restatements of the stimulus can also be interpreted as characteristics of liminality such as brick wall stuckness or analysing the problem.

Other transcripts in which respondents began by attempting a challenge other than the one that was posed could be interpreted as failures to perceive the threshold rather than attempts to avoid it; when the challenge was presented again in a modified formulation these respondents showed no reluctance to enter liminality. For example, the strategy used by some respondents of describing rather than explaining could be interpreted either as an avoidance strategy or as a type of explanation as proposed by Gilbert *et al.* (1998). Constructivist learning theories allow that a student may fail to perceive a cognitive conflict because 'observation is influenced strongly by the existing ideas of the student' (Bell 2005, 63). Other sources that describe a misperception of a cognitive challenge include Chinn and Brewer (1993, 2 - 28); Simons and Chabris (1999); Sutherland (2007, 65); and Perkins (2000, 46 – 48).

Burbules (2000, 179), whose 'aporia' seems to have points of analogy with liminality, suggests that one of the reasons that a learner will say 'I don't know' is to mean 'I don't care, leave me alone'. In this study M4 appeared to admit defeat within ten seconds of encountering the stimulus. However, he interspersed his protestations of ignorance with phrases that suggested that he was still attempting to come up with ideas: 'I think that it's ... yeah ... no ... I dunno ... umm ... [1.4s] ... I've

got no idea ... 1.8s ... I think it's ... 1.6s ...' etc. Boggy ground stuckness seems a better interpretation of this than surrender.

In summary this study found no unequivocal cases of respondents deliberately pursuing a strategy of avoiding the threshold or 'refusing the call'. This may be due to sampling issues. These learners studied the same subject with the same teacher in the same educational institution; they had similar levels of prior academic achievement; they had broadly similar socioeconomic profiles; they were between 16 and 18 years of age. They had been informed that they would be questioned on their understanding of physics and they were all volunteers which suggests they felt sufficiently confident to expose any gaps they might have in their understanding. This might also account for their behaviour during the interviews: none seemed distressed and most smiled and laughed. Most were genuinely puzzled by the challenge and many became stuck and failed to resolve it for themselves. Nevertheless all of them were prepared to enter the liminal zone.

However, if this finding that respondents did not avoid the threshold can be generalised then it emphasises the need to ensure that the experience of liminality is interpreted from the perspective of the respondent undergoing liminality. When I was a physics teacher I would have assessed a pupil who used description as an explanatory technique as having an imperfect understanding. I would have used a learner deficit model to explain why some learners failed to pass through the thresholds I had set up. However the findings of this study suggest that, seen from their point of view, learners are engaging with the thresholds as they see them.

This has two immediate implications. If the failure to perceive a threshold is due to the threshold being insufficiently made clear rather than because of poor perception on the part of the learner; there are implications for pedagogy. These will be addressed in the next chapter (section 7.2.1).

The second implication is that in this study the cognitive challenge experienced by the respondents is not the physics-based stimulus they read aloud but rather the mismatch in explanations between what they offered and what they believed was required. In the last chapter a number of explanations were identified. In the next section these will be compared with the explanations suggested in the literature.

6.2: Types of explanation

Using grounded theory, the explanations used by the respondents in this study were categorised. The classification system was then compared with those proposed by Martin (1972), by Gilbert *et al.* (1998), and by Brewer *et al.* (2000).

Martin (1972, 45 - 50) studied explanations in the context of science. Scientists may 'clarify' what something means, for example by offering a definition; this seems similar to the labelling found in this study. They may 'justify' by 'citing evidence'. They may 'give a causal account' of an effect; this seems to be equivalent to the 'material' explanations found above. Martin's scientists may cite a theory, he gives the example of explaining Kepler's Laws using Newton's theory of gravitation; this seems analogous to the 'formal' explanations described in this study. Finally Martin tells us that a scientist might 'explain the operation of something ... by explaining its function'; this equates to 'explanation by design'.

Gilbert *et al.* (1998) also offer a five-fold typology which they helpfully link to that of Martin (1972). Their first type of explanation is ‘intentional’, an attempt to explain why the researcher carries out the inquiry. They link this to Martin’s justification because an appeal to intention is a ‘justification of actions’. Martin does give ‘refusal to engage in research’ as an example of ‘justification’ but he makes it clear that justification has a wider scope; an alternative example is offering evidence to support a belief. The second type of explanation offered by Gilbert *et al.* (1998) is a ‘description ... an account of its behaviour’. They link this to Martin’s clarification although a description and a definition seem different. The third explanation in this typology is ‘interpretive’ which they describe as ‘the naming of entities within the phenomenon’ and link to Martin’s theory citation. Fourth, they offer ‘causation’ based explanations (matching Martin’s causal) and finally they propose ‘prediction’, which they also match with Martin’s causal.

Brewer *et al.* (2000, 284 - 286) suggest ‘causal or mechanical’, ‘functional’, ‘intentional’, and ‘formal or mathematical’.

These systems of categorising explanations are compared in Table 10.

This study	Martin 1972	Gilbert *et al.* 1998	Brewer *et al.* 2000
By decree			
Otherwise			
Describing		Descriptive	
Labelling	Clarification		
	Justification		
By intention		Intentional	Intentional
By design	Functional		Functional
Teleological explanation			
Formal	Theory citation	Interpretive	Formal/ mathematical
Saving the phenomena			
Material	Causal	Causal Predictive	Causal/ mechanical
Explanation within limits			

Table 10: Comparison of different schemes used to categorise explanations

The evidence of this study suggests that the participants used more types of explanation than those favoured by the authors of the studies cited above. This might be because different authors have different perspectives; any attempt to produce an overarching scheme inevitably loses these nuances. An alternative interpretation is that Martin 1972, Gilbert *et al.* 1998 and Brewer *et al.* 2000 were offering a prescriptive list of explanations. It could be argued that the explanations I have labelled as 'by decree' ('It is because it is') and 'otherwise' ('It is because it could not not be') possess little of what Carey (2000, 14) calls 'explanatory depth'. The respondents in this study certainly seemed eager to find alternative explanations after having advanced these first explanations. Nevertheless, these explanations were offered. Furthermore, even an 'explanation by decree' ('it just happens') is not unknown in science. For example, Bohr's model of the atom included the stipulation that electrons travel in fixed orbits despite Bohr being unable to justify this requirement; it was asserted 'by fiat' (Farmelo 2009, 71). Furthermore Ahn and Kalish (2000, 202) point out there is a 'problem of potentially infinite regress' in that every explanation can require a deeper explanation in a chain which ends only when the explainer chooses to call a halt by appealing to some sort of First Cause. For example, the material explanation that the dog will continue to sink into the bed until the springs are compressed to the point that they push back with a force equal to the dog's weight could be challenged by asking: why do the springs behave like that. This might be explained by talking about the atoms inside the springs and so on but at some point one will end by stating that this is how things behave. It could thus be argued that all explanations ultimately end in some sort of explanation by decree.

In section 6.1 above it was suggested that M1 was using the description of what happened as a way of explaining how it happened. Gilbert *et al.* (1998) suggested that something could be explained by describing its behaviour. It was therefore decided to reclassify 'describing' as a type of explanation. In common with other 'low-level' explanations, it was noted that many of the respondents were not happy with their response when they described and sought better ways of explaining. Simon (2000, 24 - 28) sees this as a general phenomenon: 'we want explanations' even at the expense of adding unobservable theoretical entities because explanations can be extrapolated into new contexts. If description is classified as a type of explanation this justifies the decision not to see it as an attempt to avoid the threshold.

Ogborn *et al.* (1996, 14, 7) suggest that much explanation in science classrooms involves labelling, for example 'the bending of light as it enters a transparent material such as glass or water is called "refraction". A process becomes a noun.' Ausubel and Robinson (1969, 63) suggested that attaching a label to a concept was one of the steps undertaken when a learner formed a new concept. At its best labelling involves the creation of a theoretical entity which enables further explanation; if this does not happen labelling can be no more than the creation of a name.

A number of respondents seemed to ascribe intention, or at least quasi-conscious awareness, to inanimate objects. Gilbert *et al.* (1982, 250) noted that one aspect of what they call 'children's science' is that objects are personified. The ascribing of intentionality to objects is a common feature of pantheism and fairy tales. Egan

(1997, 71 - 72) points out that to a child of five ‘magic is entirely unobjectionable’ and ‘in some cultures ... fantasy and magic perform explanatory work.’

An ‘explanation by design’ is a version of an intentional explanation except that the intentionality is ascribed to a designer; for example, a surface prevents an object falling through it because it has been designed to resist forces. Searle (2006, 17) points out that an explanation by design presupposes social agreement over values; if our society valued death over life people might consider a beating heart to be dysfunctional. ‘Teleological’ explanations, which have been categorised separately in this study although in other categorisations they may be regarded as a subset of ‘explanation by design’ or ‘intentional explanation’, suggest that objects ‘seek’ a ‘desirable’ endpoint; such as an electron returning to a stable orbit after having been displaced. Intentional explanations, explanations by design, and teleological explanations are categories with considerable overlaps and it is understandable that alternative classifications of explanation may group them together.

Ogborn *et al.* (1996, 11) suggest that formal explanations ‘may begin life as law-like patterns, but often develop a life of their own in explanations’. A formal explanation is a description of an observed regularity rather than an expression of cause and it seemed that at least some of the participants in this study recognised this; for them the formal explanation was not enough.

Saving the phenomena type explanations were observed when M1 invoked ‘the quality of the spring’ and ‘little structures’ in wood that act like springs; in both cases he seemed to be creating a theoretical entity. This could be regarded as similar to

the ‘labelling’ category described above. It can result in what Gilbert *et al.* (1982, 250) describe as ‘giving an unwarranted physical reality’ to a concept (the example they give is ‘coldness’).

Ahn and Kalish (2000, 201) suggest that material explanations seek to offer a causal mechanism ‘which can distinguish cause from correlation’ and which does not rely on any form of intentionalistic intervention. Material explanations seemed to be favoured by respondents in this study.

‘Explanation within limits’ was a category generated from the data because so many respondents seemed to tend to dwell on limiting cases. For example, M3 and F2 were concerned with the elastic limit of springs, and M1, F2 and M5 worried about the bed or the floor breaking. This might simply reflect the fact that young people tend to enjoy considering extremes: ‘Why is the average ten-year-old so interested in who was the tallest person who ever lived?’ asks Egan (1997, 84). An alternative interpretation of ‘explanation within limits’ explanations might be that they are hybrids between a teleological explanation and an ‘otherwise’ explanation: equilibrium must be achieved because otherwise the end result would be catastrophe. If they were so classified, ‘explanation within limits’ explanation would not need a separate category.

One explanation in the table was not included in the list of explanations in this study: Martin’s ‘Justification’ by which he means giving the evidence for something. It could be argued that this is an encompassing concept which could be instanced by other explanations given, for example labelling (‘because it is in equilibrium’), formal

explanation (‘because of Newton’s Third Law’), by intention (‘because the bed tries to balance it’), or even by decree (‘because that is what happens’).

6.2.1: Hierarchy of explanations

The ‘hierarchy’ of explanations proposed in this section is not intended to prescriptively suggest that some explanations are better than others but to descriptively state that in the context of this study many respondents appeared to value some explanations over others. This was shown because, having come up with one sort of explanation, they persisted seeking another explanation.

A number of writers have noted that some explanations are commonly deemed better than others. Piaget (1974, 4) points out that some explanations precede others both ‘in history and in individual development’. Ogborn *et al.* (1996, 139) suggest that explanatory narratives start with the everyday and evolve to become more abstract; presumably they intend the evolution to imply progression. McCauley (2000, 62 - 75) suggests that scientific explanations, though based on the way children explain things, are less 'natural' than the explanations of, for example, religion which rely primarily on narrative; presumably the degree of naturalness implies a hierarchy. Although Gilbert *et al.* (1998, 13) point out that the appropriateness of an explanation depends upon context, including who is asking the question and when it is asked, they go on to suggest criteria to determine the power of an explanation; these criteria are plausibility, parsimony, generalizability and ‘the number of predictions which it supports’. Posner *et al.* (1982, 215) seek ‘elegance, economy, parsimony, and not being *ad hoc*’. Brewer *et al.* (2000, 282)

emphasises internal consistency, external consistency with the evidence, scope, simplicity and plausibility. Simon (2000, 22 - 26) suggests that explanations are valued more highly than 'descriptive laws' even though the latter are able to make predictions because explanations involve theoretical constructs which enable them to be extrapolated into new contexts.

An alternative interpretation is that the respondents in this study had already learned one of what Perkins (2006, 44) calls 'threshold epistemes' that characterise physics; they understood that there is within physics an implicit preference for material explanations and, having assessed the context of the interview, they perhaps temporarily adopted this preference. Some learners also studied humanities and arts subjects; it would have been interesting to compare explanatory hierarchies elicited from the same learners within different disciplines. It would also be interesting to explore explanation types elicited from students from non-western cultures; Cobern (1998, 14 - 15) suggests that standards of rationality may be culturally determined. Such investigations are left for future research.

6.2.2: The cause of the cognitive challenge

Whatever the reason for such an explanatory hierarchy might be, there seemed to be evidence that it did exist and that the cognitive challenge seemed to be between the explanation that was available to the respondent and the explanation that they felt was needed. Rather than a conceptual mismatch it was a mismatch at the level of the 'episteme' (Perkins 2006, 44) or what Land *et al.* (2005, 55) call a 'threshold conception'. As Perkins (2006, 41 - 42) suggests: 'the disciplines are more than

bundles of concepts. They have their own characteristic ... system of ideas or way of understanding that allows us to establish knowledge.'

However, the literature review suggested that not every cognitive challenge, such as a mismatch between the explanations available and desired, necessarily resulted in an attempt at resolution. Since the world is 'full of ambiguity and uncertainty' (Collins *et al.* 1975) there are inconsistencies in our concept networks (Abelson 1959, 344; Driver, Asoko *et al.* 1994, 7); examples were given by Vosniadou *et al.* (2008, 7), Gilbert *et al.* (1982, 252) and Weinberg (1987, 7). Gilbert *et al.* (1982, 247) point out 'successful learners use teacher's science when required in tests and examinations, but still retain children's science in dealing with many everyday situations.' Finally, Driver, Asoko *et al.* (1994, 8) report that 'everyday reasoning is characterised by pragmatism. Ideas are judged in terms of being useful for specific purposes or in specific situations.'

There was evidence in this study too of learners being incoherent in their use of explanation. For example, F2 has a moment of enlightenment when she states 'So that's how it adjusts! ... It just matches ... whatever electrons are pushing down ... it push, it has to push up ... otherwise, cause that's just how electrons work.' She is excited that she has provided a material explanation for the way the bed adjusts to the weight of the dog but that is underpinned by an explanation by decree: 'that's just how electrons work.' Later she reverts to thinking at the spring level and her next eureka moment involves an explanation by intention in which the spring 'wants to go back to where it originally was'. Similarly, M2 invokes the concept of 'the ideal position for an electron to be in ... the point at which ... they're stable'. These

examples illustrate what Ahn and Kalish (2000, 202) call the ‘problem of potentially infinite regress’: every explanation is founded upon another. In the end every explanation in physics depends upon a description of how something more fundamental behaves and, until such time as an even deeper level of explanation is discovered, the ultimate explanation must always be one of decree: it behaves like that because it behaves like that. The learners in this study were prepared to ‘nest’ intentional explanations and explanations by decree within material explanations and they were prepared to tolerate such nestings to some extent.

6.3: Strategies

In order to improve their explanations and resolve the cognitive challenge the respondents made use of a number of problem solving strategies.

6.3.1: At the threshold: highlighting

Dewey (1910, 72) suggested that the first two steps in problem-solving involve perceiving a difficulty and then locating and defining it. It has already been suggested that the technique of highlighting, described in section 5.3.1 above, assisted some respondents to define the problem to themselves. This strategy involves restating the problem in a modified form; the modification could be as simple as whispering it, or repeating only a part of it, or using hesitation to break it into semantically coherent chunks. This strategy observed also by Patrick *et al.* (2015, 754), might be an example of what Cosejo *et al.* (2009, 573) call

‘restructuring’ and Perkins (2000,148) calls framing. Foley (2014, 53) describes it as ‘coming to terms with the unfamiliar territory and better articulation of what is causing trouble.’ On the other hand, the use of whispering and repetition suggests the use of reflective self-dialogue (see section 6.4 below).

The strategy of ‘denial’ in which the respondent questioned the premise of the challenge can be seen as another way of focusing attention on a part of the stimulus rather than an attempt to deny the threshold.

6.3.2: The Edison

Other strategies are associated with travelling through the liminal experience. One of these is the ‘call to action’; some respondents used words such as ‘well’ or ‘so’ in what appeared to be attempts to initiate thoughts. One respondent explicitly (and perhaps others implicitly) used the ‘Edison’, a deliberate strategy of listing everything that you can think of in the hope that you might recognise one as the solution in the same way that Edison systematically tested hundreds of materials in the search for a material to use as the filament for a light bulb. This strategy is described by Perkins (2000, 52) as ‘getting systematic about surveying all the possibilities’; it is also listed by Entwistle (1997, 54) who says that some learners ‘search their memory intensively … to see if they can recall anything that might be of help’.

It might be argued that the Edison is a systematicised form of the exploratory thinking involved in generating and assessing ideas also shown in a less organised was in boggy ground stuckness.

There are three disadvantages of the ‘Edison’. The first is the amount of time that it takes. The second is that there is no guarantee that your previous knowledge contains the information necessary to solve the problem. The third is that even after you have generated the correct solution you must be able to recognise it. This is the problem of ‘promisingness’ discussed elsewhere in this study (section 6.5).

6.3.3: Imaginative strategies

Most of the strategies employed in liminality appeared to use imagination. Heath (2008, 117 – 118) considers that what he calls ‘radical imagination … the capacity to bring to mind totally new impressions’ gives imagination ‘a role in the formation of being’ and plays a critical part in ‘that part of the process of learning that transforms the consciousness of the learner such that he or she becomes a different person as a result of the learning’. Mezirow (2000, 20) asserts that ‘imagination is central to understanding the unknown; it is the way we examine alternative interpretations of our experience by “trying on” another's point of view.’ Driver (1983, 45) points out that ‘before pupils can be expected to abandon their old ideas, they have at least to be able to comprehend the ones which are presented to them. This may involve an imaginative act to consider the possibility of the new idea without necessarily believing it to begin with.’

A number of respondents made use of analogy. There was an implicit invitation to do so when I asked the respondent to generalise from the ‘dog on the bed’ to a person standing on a floor or pushing down on a tabletop. Finke *et al.* (1996, 177) tell us that ‘analogies provide another means for creatively exploring solutions to problems,

especially those that are ill-defined.' One participant spontaneously and explicitly linked the ability of the bed to push upwards with the hydraulic upthrust he had learned about a few days earlier. A number of respondents seemed to be discussing pressure when they suggested that the causal mechanism at work was to do with the way the dog or meerkat's weight was 'spread out' on the bed.

An analogy requires a learner to extract a feature of the stimulus and then search for that feature in other situations. What is needed is an imagination which 'pierces through dissimilarity to some underlying oneness in which qualities the most remote cohere' (Lowes 1978, 105). The problem lies in identifying which characteristics are relevant. Bishop (2006) recommends both that the basis for the analogy, 'that which is known', should be familiar to the learner and also that the links between this and 'that which is unknown' should be made clear and explicit. Lee (2002) suggests that an analogy needs both an anchor, something which is acceptable to the old learning and a bridge to move from old to new learning.

In this study those respondents who seemed to have solved the 'dog on the bed' challenge were encouraged to extend their ideas to considering either a person standing on a floor or someone pushing down on a table; it was hoped they would perceive an analogy between the springs in the mattress and the interatomic bonds in the other surfaces. In fact, most respondents found this extension extremely difficult. Their analogising seemed to be 'superficial' (Finke *et al.* 1996, 177). They saw the other situations as being different because the other materials were stiff and they had no springs in them, as M4 explained 'the floor's made of concrete, it doesn't push up ... well it does but it doesn't ... It's not stretchy'. If there was a similarity it

was because of the carpet on the floor which, M1 explained, ‘gives it a little bit of buoyancy, not buoyancy, a little bit of err .... cushion’. This seemed to be an example of what Driver (1983, 38) described: ‘Even when pupils appear to have understood an idea or principle, they revert to alternate frameworks for their intuitions when faced with slightly novel tasks.’

When analogising it is common for the analogy to be drawn from everyday experience. Some of the respondents were prepared to explore ideas from regions of uncertainty. For example, F2 explored ideas using a deliberately different point of view. Some respondents considered things that they knew to be incorrect. Hofstadter (1980, 642) suggests that counterfactuals allow us to open up possibilities rather than barriers. Some respondents deliberately imagined the impossible, a strategy dubbed the ‘White Queen’. Pope and Gilbert (1985, 261) suggest that the ability to entertain incompatible ideas might be one reason that children, whose constructs are less tightly integrated, may be better at learning than adults.

Having generated impossibilities some respondents then used the *reductio ad absurdum* of Sherlock Holmes to eliminate them from consideration. This strategy, however, can only be successful when one has a limited number of alternatives. Thus one can determine that the weight of the dog and the reaction force of the bed must be balanced because there are only two alternatives available, that the dog’s weight is greater than the reaction force in which case the dog will crash through the bed, or that his weight is less than the reaction force in which case he will be propelled upwards into the air. It is more difficult to explain how the forces come to

be balanced because there are many possible mechanisms of the balancing and it would be difficult to be certain that one had explored them all.

Finke *et al.* (1996, 175) found that 'representing or restructuring the problem in the form of mental images' was a strategy often successfully employed by expert problem solvers. In this study too, the most successful of the imaginative strategies employed visualisation: respondents visualised what happened as a sort of mental movie and then played it in their heads. This was called the 'frame by frame' strategy; three respondents (M1, F2 and F4) hint at this and two (M12 and M17) offer more substantive evidence of using this strategy. M17 cast himself in his own movie and considered what happened from a first person point of view which rapidly enabled him to understand the situation. There was evidence for this in the literature: Finke *et al.* (1996, 178) describe 'imagining himself or herself as some entity that plays a part in the problem' as a type of analogy. This sort of visual imagining as a problem-solving strategy is like that reported by Kekule when he dreamt of the structure of benzene (although Gruber (1995, 411) casts doubt on the veracity of Kekule's story). It may also be what Savin-Baden (2008, 76) had in mind when she suggested that 'positioning oneself in learning spaces may be the most effective means of overcoming stuck-ness and moving over a threshold.'

6.4: Reflective self-dialogue

The most prevalent technique employed within liminality was reflective self-dialogue. There was evidence for this in all but one of the transcripts. Because it is so widespread I have interpreted it as a feature of the liminal experience rather than a deliberative strategy.

Schwartzman (2010, 34 – 35) describes reflectiveness as ‘the mechanism of transformative learning.’ She locates reflection between ‘confusion’ and ‘expanded knowing’; it follows on from the awareness that the old learning is no longer adequate; it is followed by a ‘sudden ... unstructured event ... corresponding to the newly reformulated meaning frame’ She states that ‘the mechanism of reflectiveness is not well understood’ although it involves an ‘examination’ of one’s meaning frame. Illeris (2007, 65 – 71) points out there are two types of reflection. One, which he calls ‘afterthought’ involves looking back on something and the other, ‘reflectivity’ ‘involves one constantly putting what one learns in relation to … one's understanding of oneself’.

Although reflection had been predicted, no suggestion that during liminality learners talked to themselves had been detected in the threshold concept literature. Part of the second literature review was therefore devoted to seeking sources which might support this aspect of reflective self-dialogue.

Piaget (1959, 9 - 18) believed that thought-as-inner-speech was responsible for the ‘ego-centric’ talk of young children which he recorded as they played and solved problems; he noted both ‘monologue’ and ‘dual collective’ forms and he recognised that such private talk could persist in ‘men and women of a puerile disposition ... who are in the habit of thinking aloud as though they were talking to themselves’. However, most recent research believes the opposite: that thought-as-inner-speech develops from the private talking-aloud-to-themselves of young children. Vygotsky found that young children often talked to themselves as they sought a solution to a

problem whilst older children ‘thought (which was indicated by long pauses)’; he concluded that this ‘private’ speech ‘does not simply atrophy but “goes underground”, i.e. turns into inner speech’ (Vygotsky and Kozulin 1986, 30 - 34). Vygotsky’s ideas seem to be borne out by more recent researchers; for example Berk and Landau (1993, 556) found that ‘audible self-directed utterances are abbreviated and internalized as silent verbal thought’. Davis *et al.* (2013, 562) found that ‘the private speech of children with imaginary companions is more internalized than that of their peers who do not have imaginary companions’; a longitudinal study might elicit potential consequences at a later age of any such difference in internalization.

Despite starting from the assumption that ‘the primary function of speech is communication’ (Vygotsky and Kozulin 1986, 7), Vygostsky appears to have believed that inner speech was essentially a monologue (Vygotsky and Kozulin 1986, 254). This may reflect the contemporary belief that consciousness is unitary. However, the fragmentary and multiple consciousness suggested by, for example, Dennett (1993), Fernyhough (2017, 209), Bakhtin (according to Holquist 1990, 22) and Clark (2016), allows at least the possibility of dialogic inner speech. The phenomenon described above as reflective self-dialogue is evidence that at least some inner speech is dialogic.

It is proposed that reflective self-dialogue is therefore the ‘underground ... inner speech’ observed by Vygotsky. Davis *et al.* (2013, 562) found that ‘as children get older, their private speech becomes increasingly more difficult to understand because it is both quieter (whispering and muttering) and more abbreviated and

condensed (occasional words rather than complete sentences)'. Vygotsky also noted that 'inner speech appears disconnected and incomplete' (Vygotsky and Kozulin 1986, 249) and suggested that the whispering may be due to an increased perception of 'social pressure' (Vygotsky and Kozulin 1986, 91). Whispering and muttering were also observed in this study. Vygotsky's objections to an 'intermediate whispering stage' may have been because this view was advanced by the behaviourists of his time who viewed thought in purely mechanical terms (Vygotsky and Kozulin,1986, 38). Under the circumstances of the think aloud requirement it would appear that some respondents reverted to the whispering and muttering stage of the developmental progress from social speech to egocentric speech to reflective self-dialogue.

The consequence of developing thought-as-inner-speech from talking-aloud-to-yourself would probably lead to different individuals experiencing different amounts of thought-as-inner-speech as adults. Bereiter (2002, 69) reports: 'the experiencing of an inner life appears to vary considerably as between introverts and extraverts, women and men, the educated and the uneducated' and Fernyhough (2017, 64) suggests considerable variation between people both in terms of to what extent their thoughts involve inner speech and also how dialogic it is.

Talking to yourself seems to be a feature of problem solving behaviour. Tajika *et al.* (2007, 222 - 233) state that 'a number of studies have shown that students generally learn better when they explain tasks such as expository texts and physics problems to themselves.' Ainsworth and Burcham (2014) find that 'encouraging learners to explain material to themselves as they study can increase their understanding'.

Vygotsky observed children at play and found that when they faced obstacles (for example a crayon of the 'wrong' colour 'the coefficient of egocentric speech almost doubled ... the child would try to grasp and to remedy the situation in talking to himself' (Vygotsky and Kozulin 1986, 31). Fernyhough (2017, 51) also found that children talked to themselves more as tasks grew more difficult (up to a point after which the amount of private talk declines) and that 'children who used more self-regulatory private speech solved the puzzles more quickly'. He further notes that notes that 'I myself am most likely to experience a full-blown inner conversation when I am grappling with a dilemma' (Fernyhough 2017, 252). Searle (2006, 19) suggests a reason why talking to yourself would be a feature of problem solving: he asserts that language enables the representation not only of 'what is the case but what was the case, what will be the case and what they would like to be the case. Even more spectacularly, they can lie'. This is compatible with the observation above (section 6.3.3) of imaginative problem solving strategies such as visualisation and imagining the impossible. Fernyhough (2017, 15) believes that it is within a dialogue that we can open our minds to 'alternative perspectives that might be one of the hallmarks of creativity'.

This offers a *post-hoc* justification for using the 'think aloud' method, although it might be argued that the respondents might not have developed a discipline-focused language with sufficient nuance to adequately communicate their unspoken thoughts. There is evidence for this point of view in the pauses which might be regarded as representing the difficulties participants had in putting their thoughts into the appropriate words. An alternative perspective suggests that if the respondents do

not use the ‘proper’ academic words this is evidence that they are not thinking using the proper academic words.

Following this latter interpretation it might further be suggested that problems might be solved better if the internalisation of inner speech was reversed. Vygotsky noted that private speech ‘dies out at the threshold of school age’ (Vygotsky and Kozulin 1986, 31) and Fernyhough (2017, 250) proposes that ‘one of the reasons why private speech ‘goes underground’ in middle childhood is that talking to yourself out loud is rarely sanctioned in Western schools’. Perhaps teachers should implement a ‘reverse Vygotsky manoeuvre’ and encourage problem solvers to talk out loud (or at least whisper) to effect transformative learning within liminality. Although correlation is not causation, the observation that educated people have more reflective self-dialogue than uneducated people (Bereiter 2002, 69) might be explained if reflective self-dialogue aids problem-solving and therefore those who use it find that it helps them to learn more quickly. O’Connell and Dyment (2011, 49 – 56) have advocated the use of reflective journals to ‘help make learning more deliberate’ and ‘provide a venue for struggling with questions and potential solutions to problems’; this sounds like a written version of talking out loud while experiencing liminality.

In the present study the evidence suggests that reflective self-dialogue was used by the respondents to evaluate whether an answer was correct, or whether it was complete; to decide whether or not they were stuck; to generate ideas by asking questions of themselves; and to restate part of a stimulus, perhaps in order to direct their attention to a key feature of the stimulus. Similar functions have been described in the literature. For example, Gibbs (1994, 373) describes how a worker, having

made an error with his work, sarcastically told himself ‘Nice job, Greg’; this seems similar to an evaluation of an answer.

Fernyhough (2017, 252) suggests that reflective self-dialogue is presently under-researched. It would be interesting to know whether an inner monologue transforms into a dialogue as a learner enters a liminal experience. Further studies might involve neuro-imaging. Although Alderson-Day *et al.* (2016, 110 - 118) note that ‘most neuroimaging studies to date have operationalized inner speech as a unitary phenomenon equivalent to a first-person monologue’ they suggest that it might be possible to distinguish monologue and dialogue neurologically. This is an area for further enquiry.

6.5: ‘Possible breakthrough ideas’ as transformations

It was mentioned in section 2.4.4 that some writers (for example, Irvine and Carmichael 2009, 106; Orsino-Jones 2010, 293; Easdown 2014, 44; and Shanley and Dalley-Hewer 2017, 16) associate transformative learning within liminality with 'eureka' moments. The typical characteristics of ‘eureka’ events were derived from the literature: ‘eureka’ moments are often but not always accompanied by visual imagery; they are accompanied by feelings of pleasure; they are sudden; they are typically unexpected, without any provenance; and their aftermath was a feeling of certainty.

In this study evidence was found of participants experiencing what was coded as ‘possible breakthrough ideas’. In order to investigate whether these could provide

evidence for learning as transformation within liminality, a comparison was made between their characteristics and those of ‘eureka’ moments described above, although the visual aspect remained untested. Laughter and smiling was recorded for eight of the seventeen ‘eureka’ events recorded. These would seem to indicate feelings of pleasure. The absence of overt signs such as laughter cannot, of course, be used to deduce that pleasure was not felt. In other cases, ‘possible breakthrough ideas’ were heralded by repetitions; this suggested excitement which may or may not have been pleasurable. The laughter or the repetitions typically happened a few seconds before the articulation of the idea. This resonates with the findings of the insight studies quoted in section 2.4.4 that there is a period, typically of about fifteen seconds, during which the respondent has some sort of foreknowledge that a eureka is imminent. A consistent interpretation might suggest that the new idea starts at a subconscious level and rises to conscious awareness over a period of about fifteen seconds. *En route*, about five to ten seconds after its initial genesis, although the respondent is still insufficiently aware to articulate the idea, the new idea can create disfluent speech. The ‘eureka’ moment then becomes the moment at which one becomes aware that one’s understanding has been transformed. This therefore supports the notion that ‘possible breakthrough ideas’ and ‘eureka’ moments might be equivalent.

However, there do appear to be differences between ‘possible breakthrough ideas’ and ‘eureka’ moments. ‘Eureka’ moments are typically considered to involve a breakthrough in thinking that occurs ‘suddenly or discontinuously’ (Ausubel and Robinson 1969, 509), with no prior warning. Thus Kneller (1965, 54) calls inspiration

‘unforeseen’ and Metcalfe and Wiebe (2013, 238) state that ‘the phenomenology of insight-problem solutions was characterized by a sudden, unforeseen, flash of illumination’. Jaynes (1976, 43) quotes Helmholtz as saying his insights ‘arrived suddenly’ and Gauss as saying ‘like a sudden flash of lightning, the riddle happened to be solved’ and there is the well-known example of Poincare’s insight into non-Euclidian geometry occurring as he stepped into a bus. Similarly, threshold concept theory predicts that the moment of transformation is discontinuous: Wisker (2016, 167 - 168) asserts that ‘conceptual threshold crossings’ are ‘learning leaps’.

However, in my study, only about half of the insights designated as eureka moments appear to arrive ‘out of the blue’, for example when M16 leaps from thinking of ‘Newton’s Laws’ to thinking about bedsprings. In the other half the provenance of the insight thought could be traced, for example when M8’s serendipitous use of the word ‘displacement’ to mean a change in position prompted a consideration of fluid dynamics in which displacement has a different meaning. The consistent interpretation is that all ‘possible breakthrough ideas’ have provenances but that in some cases in this study there was insufficient evidence to trace that provenance. The lack of evidence stems from a flaw in the ‘think aloud’ technique is that there are pauses within the transcripts and it is not possible to suggest that there is no thought occurring during the pauses. One interpretation of the difference between ‘unforeseen’ and ‘traceable’ eurekas might be that sometimes the ideas that led up to the insight were articulated while at other times they were not. This interpretation fitted the observation that a number of the ‘unforeseen’ eureka events were accompanied by reflective self-dialogue during an immediately preceding pause. As Fernyhough (2017, 7) says: ‘thoughts are typically coherent: they fit into chains of

ideas which, in no matter how haphazard a fashion, are connected to what has come before.'

This leads to two possible conclusions: firstly, that 'eureka' events also have provenances though these might prove impossible to trace, and secondly, that 'eureka' events and 'possible breakthrough ideas' are separate constructs with different characteristics. This second conclusion is supported by the differences of scale typically involved. Many of the 'eureka' events such as that occurring to Archimedes or Kekule's discovery of the structure of Benzene, reported in the literature occur after extensive consideration of a problem, possibly extending over years. But if there is no justification for scaling up the ''possible breakthrough ideas'' identified here there is also no reason not to. Csikszentmihalyi (1990, 121) says that 'we all know the little spark of satisfaction when we remember where we put the car keys'; is this fundamentally different from a small scale eureka? Gick and Lockhart (1996, 214) suggest that 'although it is a major misunderstanding of the creative process to suppose that the discovery of complex theories happen in a single "Aha!" experience, it is the case that such an experience may be a reasonable description of critical subelements in the development of a theory.'

Furthermore, many of the insight problems use to study 'eureka' moments involve a timescale not dissimilar from that involved in this study. Such studies sometimes suggest that the final insight might have been sudden but it seems unlikely that it had no provenance. Indeed, Kounios and Beeman (2014, 88) state that 'Insight is sudden, but it is preceded by substantial unconscious processing' and Laukkonen *et al.* (2018) suggests that during insightful problem solving 'Information is integrated

below awareness'. It is therefore proposed that the apparent unexpectedness of 'eureka' events is illusory. This interpretation maintains the possibility of an equivalence between 'possible breakthrough ideas' and 'eureka' moments.

The final characteristic of 'eureka' events is that they are typically accompanied by a feeling that the solution suddenly perceived is correct: 'all of a sudden things just feel right' according to Hofstadter (1980, 50). Entwistle (2013, 131), discussing the superficially similar 'tip of the tongue' phenomenon, reports that when the word being sought arrives it appears 'not with a question mark, but with a feeling of certainty.' Gopnik (2000, 314) compares the experience of achieving an explanation with a mystical experience: 'suddenly, it all becomes clear; all at once, everything makes sense.' Gick and Lockhart (1996, 214) report that 'expert scientists often seem to have a strong intuitive sense that a newly conjectured representation will work'. Kneller (1965, 56) states that 'the creator is convinced of the rightness of his insight before he verifies it logically', although he goes on to warn that 'illumination is notoriously unreliable.' Perkins (2000, 11) considers it unusual that Darwin, conceiving the idea of natural selection whilst reading Malthus 'did not fully recognize the significance of his discovery immediately'.

But in my study, although each 'possible breakthrough idea' was accompanied by repetitions, laughter and exclamations which suggested feelings of excitement, pleasure and triumph, such premonitions of success were often fragile and transient. For example, M12 says 'Or the springs? ... [1.8s] ... No. Don't even know how to answer that'. Rather than embracing certainty, the typical response of my

respondents to a ‘possible breakthrough idea’ was to explore it further. As Dewey (1910, 76) says: ‘conjectures that seem plausible at first sight are often found unfit or even absurd when their full consequences are traced out.’ This meant that ‘possible breakthrough ideas’ were often followed by periods of boggy ground stuckness.

It was proposed that the reason why there was a difference between ‘possible breakthrough ideas’ and ‘eureka’ events in regard to the feelings of certainty was the problem of promisingness. Following the suggestion of an idea, my respondents had to consider whether it was likely to be fruitful, to consider its potential or ‘promisingness’ (Chen 2017, 255). Learners need to make an ‘evaluation about the potential fruitfulness of ideas’ (Chen *et al.* 2013, 231) so they can ‘avoid going down blind alleys’ (Chen *et al.* 2015, 348). And, as Robinson (2011, 156) says, ‘judging the value of new ideas can be difficult.’

Some authorities, for example Chen *et al.* (2015, 348), use the word ‘intuition’ to explain how some people seem to be able to choose the most promising path but Gladwell (2005) and de Bono (1986, 58) link ‘intuition’ to experience; Bereiter (2002, 113) claims that ‘like other forms of knowledge it is improvable’; Perkins (2000, 83) suggests it can be learned by ‘experiencing success and failures in making such judgements’. Something similar is found in the threshold concept literature: Efklides (2006, 53 - 54) asserts that ‘the more ignorant or unskilled one is in a domain, the more unaware what is of the conceptual and processing demands of the task ... This has an impact on the judgement of feeling of difficulty.’ If the assessment of promisingness is improvable and can be learnt this would explain experts are more likely to make the right choices than novices. This is turn provides an explanation for

why the respondents in my study, who were comparative novices, did not share the feelings of certainty of rightness when experiencing ‘possible breakthrough ideas’ as typically shown by the literature on ‘eureka’ moments. This finding resonates with that of Laukkonen *et al.* (2018) who, reviewing eureka events occurring to famous mathematicians and scientists, point out that the instant certainty they felt may have been due to ‘their considerable expertise which was developed over decades of study’.

In summary it is proposed that the ‘possible breakthrough ideas’ observed in this study are miniature versions of ‘eureka’ events. This implies both that the unforeseenness of ‘eureka’ events is an introspective misperception, and also that the feeling of certainty in rightness that typifies the ‘eureka’ event is one that is acquired with experience. Both of these assumptions are supported by the literature cited in this section.

If we can see ‘possible breakthrough ideas’ as manifestations of moments of transformative learning then the characteristics of learning as transformation within liminality are those we have described for ‘possible breakthrough ideas’ and ‘eureka’ moments: they occur within a typical timescale of about fifteen seconds; they are accompanied by feelings of excitement, perhaps pleasure; they have a provenance although this may be difficult to trace; and they are accompanied by feelings of certainty but only if the learner has developed sufficient expertise to be able to confidently assess the promisingness of their ideas.

6.6: Stuckness

There is much discussion of stuckness in threshold concept scholarship but it is usually treated as a single concept (for example, Berg *et al.* 2016; White *et al.* 2016; Meyer and Land 2005; Osmond and Turner 2010). However, Savin-Baden (2008, 81) described two types of what she calls ‘disjunction’. Outside threshold concept scholarship, Burbules (2000, 179) proposes four types of aporia: the ‘paralysis’ of ‘no path in sight’; the confusion when ‘there are too many paths from which to choose’; ‘an aporia in which one cannot recognize a path that is already there’; and a reluctance to travel a path when the destination is known and unpleasant.

6.6.1: Brick wall stuckness

This study used pause patterns to distinguish two types of stuckness. Brick wall stuckness, characterised by a long pause, resonates with what Savin-Baden (2008. 81) described as ‘a little bit like hitting a brick wall in learning’ and Burbules (2000, 179) as ‘one knows nothing, and does not know what to think or say or do next - hence, paralysis, numbness ... no path in sight’. On a long term scale this might become the ‘paralysis’ that Wisker (2014) identified in doctoral students. Brick wall stuckness is when you are trying to solve a problem and you have run out of ideas. You come to a standstill. The solution is to generate more ideas. As Kneller (1965, 82) suggests: ‘Other things being equal, the more ideas he can command, the more problems he can solve’ and Dewey (1910, 75) suggests that ‘cultivation of a variety of alternative suggestions is an important factor in good thinking.’ Csikszentmihalyi

and Sawyer (1996, 346) found that the principal strategy of nine eminently creative people was to ‘attempt to have a large quantity of ideas and select from these the good ones’. Strategies such as the White Queen or the Edison might help.

6.6.2 Boggy ground stuckness

However, the second form of stuckness identified in this study was boggy ground stuckness in which there is an alternating pattern of utterance and pause. This might fit in with the ‘sense of vague stuckness’ identified by Savin-Baden (2008, 81).

The characteristic of boggy ground stuckness seems to be that the learner is able to articulate or identify sufficient ideas but does not seem able to pursue any of them to fruition. Table 11 gives some examples.

M15	'... [3.7s] ... By ... pushing the force up like ... it spreads the weight across it or something? I don't know ... [5.9s] ... Just ... whatever pushes down it pushes back up on it.'	Pause Idea #1 (weight is spread) Pause Idea #2 (action = reaction)
M8	'... [8.9s] ... Well the ... there must, there's sort ... well is ... there is no ... motion ... so ... technically ... technically there's no acceleration on either ... part is there ... so ... but the forces are still, the forces are balanced ... [3.6s] ... And acceleration is a component of force so it must be something to do with the acceleration ... cause I, cause that, that, that just can't ... change ... so ... [3.2s] ... I don't know, so if it comes into contact with the bed ... then ... if I put my hand on this desk ... so the ... I don't know what it is about the desk that stops my hand going through, you know, apart from its mass, the mass being resistance to acceleration, you know ... so ... [6.1s] ... I don't know, maybe it's ... [4.3s] ... Except there must be some kind of, I don't know what acceleration but there has to be some kind of acceleration'	Pause Idea #1 (acceleration is linked to motion) Pause Idea #2 (acceleration is linked to force) Pause Idea #3 (mass resists acceleration) Pause Admits stuckness Pause Returns to focus on acceleration
M3	'[2.4s] ... [sounding amused] I don't know ... errrm ... errrm ... [8.8s] ... Well there's no way for it to know OK but ... [3.5s] ... [almost whispering] I don't know any...	Pause Admits stuckness Pause Idea: Moment of truth Pause Whisper suggests preceding pause contained reflective self-dialogue

	[3.1s] ... explain .... umm ... [7.1s] ... I can't remember, there's a ... there was something that we said about ... ummm ... [1.2s] ... there's a reciprocal ... [1.2s] ... that's right ... [2.3s] ... but there's no way for the bed ... or whatever surface it is ... to know ... how to adjust ... [3.6s] ... I don't know [possibly a momentary laugh] ... [4.5s] ...'	Pause Tries to access a memory Pause Idea # 2 Reflective self-dialogue Pause Returns to moment of truth Pause Admits stuckness Pause
M3	'According to Newton's Third Law ... Umm ... [3.2s] ... every action ... No That's ... Err ... That, They should be ... equal ... [2.9s] ... and they work in pairs ... [1.8s] ... so ... [1s] ... yeh, every action has an equal and opposite reaction ... so that ... action is the weight of down on the bed ... so the equal ... and opposite reaction ... has to be the bed pushing back on the dog to hold it up otherwise it just ... go through it [laugh?] ... [1.8s] ... uhh so it has always equal be equal to whatever is on it at the time ... [1.6s] ... but ... unless you take into relation potential stress where something breaks if there's too much force on it ... [1.9s] ...'	Idea #1 (Labelling) Pause Idea #2 (forces are equal) Pause Idea #3 (forces paired) Pause Reflective self-dialogue Idea #4 (if this didn't happen dog would break bed) Pause Complete Idea #4 Pause Idea #5 'potential stress' Pause

Table 11: Examples of boggy ground stuckness

Burbules (2000, 179) offers three possibilities to explain stuckness: ‘to have lost one's way, to be confused; there are too many paths from which to choose ... an aporia in which one cannot recognize a path that is already there... an aporia in which the path is apparent, but one cannot or will not follow it.’ But the evidence above suggests that an alternation of pause and idea is characteristic of boggy ground stuckness. Furthermore, the instances of reflective self-dialogue in the table above suggest that, at least in some of the pauses, the idea is then evaluated. Often this evaluation results in the respondent rejecting that idea and articulating another. Rather than dithering at a crossroads, the learner is playing a very active role in their learning. To use the multiple paths metaphor of Burbules what appears to be happening is that the learner picks a path and follows it for a short distance before deciding that it is not leading anywhere, returning to the choice point, and picking another path.

Characterising this behaviour as a type of stuckness focuses on the pauses. An alternative perspective might be developed if we focus on the utterances. From this point of view the learner is far from stuck; they have a number of ideas. As Chen *et al.* (2013, 231) point out, ‘ideas are usually in abundant supply’. This therefore contradicts the solutions proposed to brick wall stuckness in the last section. Having an idea is not the problem in boggy ground stuckness. But when there is a choice of potentially promising ideas it becomes necessary to ‘screen and evaluate’ (Treffinger 1995, 308). Burbules (2000, 182) asks how a learner can ’recognize an answer to a question?’ They have to spot what Perkins (2000, 52) calls the ‘hidden clues’ (which are, presumably, difficult to recognise because they are hidden). Driver (1983, 24) points out that learners can only base their decisions on what they already know:

‘they try to interpret the unfamiliar by analogy with familiar experiences.’ This means that they need what Davidson (1996, 147) calls ‘feelings of closeness to a solution’ or ‘feelings of warmth’; what Ippolito and Tweney (1995, 448) call ‘feelings of knowing’; what Perkins (2000, 83) calls a ‘measure of promise’; and what Bereiter (2002, 114) calls ‘confidence in understanding’. As shown above in section 6.5, this assessment of the promisingness of an idea can be difficult for novice learners.

Thus the alternation of pause and utterance that characterises boggy ground stuckness can be interpreted as the manifestation of a process in which the learner iteratively has an idea and explores it. If it is assessed as promising it might be offered as the solution to the problem. If it assessed as unpromising, the learner returns to consider another idea. This alternative understanding of the processes lying behind boggy ground stuckness I labelled ‘active exploratory learning’. This will be further explored in section 6.7.

From this alternative point of view the ‘Edison’ strategy used by F2 in which she lists all the ideas she knows and hopes that she will recognise one as the way forward could be seen as a more systematic form of boggy ground stuckness.

6.7: A reinterpretation of liminality

Following the lead of much of the threshold concepts literature, this study characterised learning as transformation within liminality. From this perspective the learner enters the liminal experience following a cognitive challenge. There follows a period of stuckness characterised by reflective self-dialogue, and pauses; the pattern of pauses led to the development of two types of stuckness: brick wall and boggy

ground. At some point the learner experienced a sudden and exciting transformation in their learning. If this was recognised as the solution to the cognitive challenge the learner then passed through the threshold; if it was unrecognised the learner oscillated back into stuckness within the liminal experience.

This account goes a little way towards meeting the aim of this study in that it provides a description of the liminal experience. However, it still leaves a number of questions unanswered. What is the relationship, if any, between the stucknesses and the transformation? Why do some learners appear to oscillate backwards and forwards across the threshold; are some transformations more reversible than others? The nearest thing to a transformation within the liminal experience seems to be the 'possible breakthrough idea': why are there differences between the characteristics of this as found in my empirical study and those of the 'eureka' moments as reported in the literature review?

One of the original features of this study was that data was collected while the respondents were experiencing liminality. Most other studies of liminality in the threshold concept literature have asked respondents to compare the pre-threshold with the post-threshold states. Perhaps it is this comparison that generates the idea that if there is a difference a transformation must have occurred. This prompted a consideration of the perspectives involved. The pre and post comparison generates a view of the learning process from outside, even if the comparison is being made by the person who went through the process and is looking back on it. This study sought a perspective that was from the point of view of the learner *in media res*. This

was why this study sought to gain an insight into episodes of liminality as they were occurring.

In 6.6.2 there was a shift in perspective. Rather than paying attention to the pauses during boggy ground stuckness, the utterances were focussed upon. This seemed to propose a less passive role for the learner, from being stuck to having ideas. Now I propose a similar perspective shift. Rather than seeing learning as a process of a learner being transformed, the new interpretation I am offering considers liminality as a period during which a learner generates an idea and then explores it. Under this interpretation, boggy ground stuckness becomes a period in which an idea is generated and then explored briefly before (usually) being deemed unpromising and abandoned. The learner then returns to the cognitive challenge to generate another idea.

This process was labelled ‘active exploratory learning’. It then became necessary to understand more clearly what is meant by ‘generates an idea’ and ‘explores it’. That these two aspects of learning might be distinct has potential pedagogical implications. It suggests that teaching learners how to brainstorm ideas might be insufficient and emphasises, for example, the need to teach learners also to recognise the promisingness of the ideas developed. This is further explored in section 7.2.1.

So how is the generation of an idea different from its exploration? Much of the literature both on threshold concepts and on concept change learning suggests that learning is triggered by a cognitive challenge and the empirical phase of this study

found evidence that supported this idea. Driver, Asoko *et al.* (1994, 6) offered as a model of this a new pupil joining a class. I will use this metaphor to explain what I mean by ‘generating and exploring an idea’. Imagine that I am the teacher of the class when the new pupil arrives. I must decide which of the established groups the new pupil should join. I will consider, among other things, where there will be most compatibility and least conflict. I make a decision, adjust one or more of the groupings in the class, and move the pupil. But this is not the end of it. I monitor the situation. If the learning of the class suffers I may move the new pupil to another group, or I may move someone else, modifying the group structure of the class. There may be consequent changes to other groups in the class. I may even speak to teachers of parallel classes to see whether I may swap one or more pupils of mine with theirs. At some stage I will decide that I have reached a position where the class runs smoothly again. The rearrangement will stop (until the next new pupil arrives).

In this metaphor the ‘generation of an idea’ is when the new pupil is placed into a group; it is the generation of a reorganised class structure. The ‘exploration of the idea’ is when the new situation is monitored.

In terms of the context of this study the cognitive challenge from the point of view of the learner was to find a way of explaining how a bed ‘adjusts’ its reaction force to match the weight of the object lying on it. Most of the respondents were able to offer a model which implicitly assumed that they bed was in some way aware, but they knew that this explanation was inadequate in the context of physics. They therefore sought a material explanation. They had to take the knowledge that the bed adjusted its reaction force, which seemed to be new in the sense that they had never

previously considered it, and to find some way of adding it to their prior knowledge. This might involve exploring their prior knowledge for ideas that might be compatible in some way with the new knowledge, for example, the bed has springs, or atoms repel, or when you climb onto a bed you bounce a little. It might also involve reorganising their prior knowledge. The end result will be a restructured knowledge: even if the new knowledge is simply added to the prior knowledge the resulting structure of knowledge will be different from what it was before. In this context the 'generation of an idea' is the generation of a reorganised structure of knowledge.

The learner will then consider this restructured knowledge. This is the 'exploration of the idea'. The learner might, for example, consider whether the restructured knowledge now makes other things that used to be satisfactorily explained harder to explain. They might consider whether the restructuring has resolved the cognitive challenge sufficiently and, if it hasn't, whether it is likely that continued restructuring along the same lines will satisfactorily meet the challenge. Such considerations will help the learner determine whether or not to return to the initiating challenge and explore an alternative way of restructuring their knowledge.

Thus, for the purposes of this thesis, I am defining active exploratory learning as an iterative process of generating a modified knowledge structure and considering the consequences. Now I shall explore whether this interpretation can explain the other characteristics of the liminal experience that I observed during the empirical stage of this study. This is a shift from my previous characterisation of learning as transformation within liminality.

It is also a continuation of the grounded theory methodology. The reconsideration of boggy ground stuckness from the perspective of the utterances rather than the pauses has led to the suggestion of active exploratory learning as what grounded theorists call a central core category. This idea of the core category appears in various versions of grounded theory and so is appropriate for my hybridised version. Thus Glaser (1978, 96) credits a core category with 'explanatory power' which in part 'explains itself'; Strauss (1978, 36) states that 'a core category … has clear implications for a more general theory'; and Strass and Corbin (1998, 146) assert that a core category should have the 'ability to pull the other categories together to form an explanatory whole'. Charmaz (2014, 107) also uses core categories although she warns that they can lead to overgeneralisation and a loss of the fine detail of the data.

6.7.1: Oscillation

It was noted in section 2.5.8 that 'oscillation' was a feature of the liminal experience claimed by a number of threshold concept scholars but there was a lack of clarity about what it involved. Most scholars (for example Land *et al.* 2014a, 201; Land *et al.* 2006, 196; Orsini-Jones 2008, 218 – 219; Thomas *et al.* 2010, 245) recognised oscillation in a learner when they appeared to grasp an idea or change a perspective or adopt a new identity and subsequently showed that they had not passed through the threshold. Thus, under the transformation interpretation oscillation is a process in which the learner appears to achieve understanding but then loses it again.

Thus when M12 says ‘Or the springs? … [1.8s] … No. Don’t even know how to answer that’ it may appear to the teacher that he has understood that the springs can be used to explain the ‘dog on the bed’ problem but that he then oscillates back across this threshold into stuckness. Another example is when M17 says ‘if, if it, if the table didn’t push back your atoms would get closer which causes ... more of a ... a ... repel from ... the atoms which ... I’m not sure [smiles]’ but then pauses for 11.7s and concludes ‘That’s not, that’s not right is it?’. The repetition at the start of this extract suggests that M17 recognised his idea as a ‘possible breakthrough idea’. But subsequently he rejects it. Again, a teacher’s interpretation might be that M17 has passed through the threshold and then slipped back.

There are problems with the transformative interpretation of oscillation. What makes a learner regress after they have experienced transformation? Is oscillation evidence that they haven’t truly been transformed? If it is, when can we be secure in saying that transformation has occurred? Had my study been conducted in a classroom situation and the teacher had interrupted after M12 said ‘Or the springs?’ or after M17 said ‘the atoms which’, would what is presently evidence for oscillation have been instead evidence of transformation?

The active exploration interpretation of learning proposes that oscillation describes the repetitive process of generating a modification of the knowledge structure, considering it, rejecting it, and repeating the process. M12 generated the idea of the springs but then rejected it. M17 was excited by the idea of linking the displacement of the atoms with repulsion but subsequently decided against it. Under this

interpretation these extracts describe the normal process of active exploratory learning. The difference is that these extracts describe situations in which the learner has generated a modification of knowledge that the teacher regards as correct. The learner, however, does not know this. ‘Most of the time the learner cannot discern the exit’, as Land *et al.* (2014b, 6) state. M12 does not know that ‘the springs’ is an avenue worth exploring. From his perspective he explored an idea which appeared to have little potential so he gave up on it prior to trying another one. M17 does not know that his idea about the atoms getting closer and therefore repelling is a promising idea. To him it is just another idea which he has proposed, considered and rejected. Nevertheless, M12 and M17 appear to the teacher to have oscillated from a post-threshold back to a pre-threshold state. The learner themselves, considering their learning journey retrospectively with the benefit of hindsight, may also see themselves as oscillating. But from the point of view of the learner in the middle of the liminal experience, they are just trying out different modifications of their knowledge structure. Under this interpretation oscillation is the external manifestation of active exploratory learning.

Understanding oscillation in this way may explain the contrasting views of oscillation found in the literature review. As shown in section 2.5.8, some writers (for example, Wood 2012; Orsini-Jones 2010, 282; Kinchin *et al.* 2010, 88; Easdown 2014, 48; and Hokstad *et al.* 2016, 326) see oscillation not as problematic but as a useful way of exploring different points of view. This interpretation of oscillation also resonates with other writers. For example, Driver (1983, 38) found that ‘even when pupils appear to have understood an idea or principle, they revert to alternate frameworks for their intuitions when faced with slightly novel tasks’. The use of the word ‘revert’ hints that

the pupils' behaviour could be characterised as oscillatory but an alternative interpretation is that the pupils do not regard the understanding they have gained as applying outside a narrow context and are therefore continuing to explore. As Driver, Asoko *et al.* (1994) note, we all have the ability to switch between possibly conflicting concept networks according to perceived context. Dewey (1910, 74 - 75) advises that a skilled thinker seeks to avoid jumping to conclusions by postponing judgement until sufficient avenues have been explored. Finally, the Edison strategy observed in this study might be regarded as displaying oscillation if one of the ideas being explored by the learner was recognised by the teacher as having the potential to solve the problem.

6.7.2 Mimicry

Active exploratory learning is the repeated modification of the structure of one's knowledge until the learner deems that the cognitive challenge that triggered the process is satisfactorily resolved. This judgement is made by the learner and might be different from that made by the teacher. This offers an explanation for mimicry.

Mimicry has been described as a strategy by which learners can avoid learning a threshold concept by learning instead an alternative method of achieving the necessary performance on an assessment. I encountered this when, as a teacher, I had occasion to teach the theory of evolution by natural selection to students among whom were some whose religious beliefs were incompatible with accepting the Darwinian theory. One of them articulated his position: he was prepared to learn what I was teaching for the sake of passing the exam but he did not intend to believe

in it. This seems parallel to the example cited by Meyer and Land (2005, 381) of males studying sexism who could produce successful assignments without interrogating their masculinity.

But these are teacher perspectives. From the learner's point of view a cognitive challenge between what they believe and what they are being taught has been resolved. As in the case of threshold avoidance where the challenge with which the respondents engaged was not always the challenge I intended so with mimicry. What has been learned is not what the teacher intended but this does not mean that learning has not taken place. One might speculate that the learning engaged in was therefore more superficial and less profound than the learning intended. One might equally well argue that for a learner to be able to reconcile what seems incompatible to the teacher suggests a more difficult learning journey and a deeper (but different) understanding than the teacher's. As Driver (1983, 34) says, 'the teacher may not be aware of ... the avenues of exploration which the pupil may have to undertake to satisfy themselves'.

Mimicry is thus a construct created by viewing education as a social reproduction device. It is one of those aspects of threshold concepts scholarship which derives from a passivist conception of the learner. It is a consequence of the tension between the understanding of a threshold concept as a gateway positioned within a prescribed conceptual landscape and the understanding of liminality as a place in which a learner makes sense of the world. This tension is signposted when liminality is viewed as a zone where a learner passively undergoes a transformation in their personal ontology as described by, for example, Savin-Baden 2017, Rattray 2016,

and Land 2016. There can be no guarantee that this personal transformation will align with the transformation desired and required by the teacher. Illeris (2007, 68) points out that learners 'might not always learn what others think they should' and Floden (1997, 17) proposed that 'given the human propensity for errors in reasoning, classroom discourse may not lead to well-justified beliefs'.

This is not to suggest that learners should be given the freedom to learn whatever they wish. In a critique of the Self-Organised Learning Environment Toolkit based on Sugatha Mitra's Minimally Invasive Education theories in which learners teach themselves using resources such as the world wide web with minimal adult guidance, Sowey (2013) found that 'the children all drew highly credulous conclusions that supported paranormal claims' when they 'investigated the question "Can you kill a goat by staring at it?"' This implies that, despite the postmodernistic rejection of 'transmissive' teaching, there is still a role for the classroom teacher to prevent learners learning the wrong thing. Driver, Squires *et al.* (1994, 6 - 11) state that 'if teaching is to lead pupils towards conventional science ideas, then the teacher's intervention is essential'; they envisage the teacher as a 'hard-pressed tour guide mediating between children's everyday world and the world of science.' It is therefore necessary to combine both constructivist and transmissive pedagogies. As shown above in section 2.1.4 such a combination of traditions is inherent (though covert) in threshold concept scholarship. It is another aspect of the tension between ontological realism and epistemological constructivism discussed in section 2.3.2. Analysed using an interpretation of learning as active exploration, mimicry does not represent a learner strategy designed to avoid challenging learning but a balance

between constructivism and transmission leading to more learner autonomy than the teacher desired.

Thus both the transformation and active exploratory interpretations of mimicry see it as a problem for the teacher concerned with the social reproduction of knowledge. The difference is that the active exploratory interpretation sees mimicry as inevitable because when learners construct their understanding they do so at least partly on the basis of their previous understanding. The transformation interpretation sees mimicry either as a strategy on the part of learners to avoid being transformed or as a failure of those learners to be transformed. These will lead to different pedagogical responses which will be explored in the next chapter.

6.7.3: Brick wall stuckness

Brick wall stuckness was a prominent characteristic of the liminal experience. Under the transformative interpretation this has been described as a form of mental paralysis, for example by Savin-Baden (2008, 81), Flanagan and Smith (2008, 98), and Burbules (2000, 179). There seems to be no clear relationship between the stuckness and the subsequent transformation although just before his oscillatory/ transformative statement of ‘the springs?’ M12 had paused for 12.8s before saying ‘... I don’t know how it adjusts its reaction force. ...’

At first sight the active exploratory interpretation fares even worse: no progress is being made when the learner is supposed to be iteratively modifying knowledge and considering the consequences. Perhaps it is the metaphor of the brick wall which is

misleading: it suggests that the learner is not thinking because they are not uttering ideas. A better metaphor might be that the learner is treading water: they are continuing proactively to explore even though they appear to an outside observer[6] to be making no progress. At the end of M12's long pause he swiftly moves to uttering a (potentially) transformative idea. In fact, although sometimes a respondent admitted defeat, almost every example of what was previously called brick wall stuckness was terminated by the respondent expressing a thought which was then elaborated and pursued. This undermines the idea of mental paralysis. Other examples which suggest thought continuing during long pauses include respondents using the word 'so' as a lexical filler. For example, M1: 'So ... [6.9s] ... [very quietly] I don't know ... [2s] ...' or M5: '... [3.4s] ... so ... [3.1s] ... yeah ... I don't I don't really know how to ... go about this one'. It has been established that 'so' can be used to initiate thought. Although these examples were previously interpreted as failed attempts to initiate thought it is also possible that thoughts are being initiated but not articulated.

It was suggested in section 6.6 that one of the differences between brick wall stuckness and boggy ground stuckness is that in the first case the learner has no ideas and in the second case the problem is in the selection of the right idea. This interpretation suggests that these differences depend on where in the active exploration process the learner is. Are they considering which part of their prior knowledge seems most compatible with the new knowledge or have they made the modification and are trying to assess whether the consequences suggest that a

[6] The paralysis mentioned by Wisker (2014) is based on the self-report of doctoral students. It is not just external observers who see treading water stuckness as paralysis.

solution has been found or whether they will have to move the new knowledge elsewhere? This interpretation will also help to explain why treading water stuckness often occurs immediately or soon after the challenge is perceived.

Furthermore, the active exploratory interpretation suggests an explanation for why some pauses are so long. Returning to the M12 example, he starts the pause considering a problem in physics and he ends it by remembering something that he knows about beds. It is likely that M12's knowledge of beds is conceptually distant from his knowledge about Newton's Third Law. Returning to our analogy, before the newly arrived student is allowed to join any group the teacher will have considered where they should be placed. This consideration might start with a simple solution (perhaps the nearest empty seat) and subsequently more elaborate solutions. The student will then be directed where to sit (which, in the metaphor, is the generation of an idea) and then teacher will continue to monitor the reorganised class (which, in the metaphor, is the exploration of the idea). This analogy therefore suggests that the learner will first try to attach the new knowledge to whatever prior knowledge structure is most available at the time. As modifications are rejected the learner will need to seek out areas of prior knowledge that are more conceptually distant but still considered relevant. The longer pauses of treading water stuckness might be because learner has to search further afield before finding a potentially acceptable modification of prior knowledge; this would be manifested as a longer search before the generation of an idea. This would also help to explain why many of the longer pauses occurred immediately after the stimulus.

6.7.4: The ‘eureka’ effect

A crucial test of the transformative interpretation must surely lie in the moments which seem to be when the transformations occur. As discussed in section 6.5, these are the ‘possible breakthrough ideas’. But there are two differences between the ‘possible breakthrough ideas’ in my study and the accounts of ‘eureka’ events found in the literature. Firstly, my respondents often lacked the feeling of certainty in their solutions. The transformative interpretation can explain this using the concept of promisingness; the novices in my study were less able to assess the potential of an idea compared to the relative experts in the ‘eureka’ literature. However, the transformative interpretation could not explain the second difference: why there is widespread agreement in the literature that ‘eureka’ events comes ‘out of the blue’ whilst about half of the ‘possible breakthrough ideas’ in my study had traceable provenances.

The model of active exploratory learning requires the learner to consider each modification made to knowledge to see whether it will sufficiently resolve the cognitive challenge that initiated the liminal experience. Kunda (1990, 481) points out that a key part of that consideration will involve balancing goodness of outcome. A learner does not want to waste time and effort following a wrong idea but neither do they want to give up if the idea might later prove to be correct. They have to decide whether the modification already made is good enough, or whether an adjustment of the modification will be good enough, or whether to start again. This model provides a rationale for ‘promisingness’.

The active exploratory learning interpretation can also explain why some provenances are traceable and others are not. It was suggested in the previous section that treading water stuckness occurred when the learner had to search further afield to find a satisfactory modification of their knowledge. Let us return to the 'new learner in class' metaphor. If the easy solution is not satisfactory the teacher will try more complex reorganisations of the class. They may build a reorganisation on an earlier one. They may involve other parallel classes. It is intuitively likely that the greater the original mismatch the more complex the modification process. When a satisfactory arrangement is finally found, the chain of moves leading to the solution is likely to be difficult to trace. It is exactly those problems that are most difficult that are likely to be most difficult to provide a traceable provenance. This offers a reason why the 'eureka' moments in the literature, which typically occur after substantially longer periods of time than allowed for in this study, are less likely to have traceable provenances than my 'possible breakthrough ideas'. As Kinchin *et al.* (2010, 87) state: what appears to be intuition may be 'simply the poorly articulated links between chains of practice and underlying networks of understanding.'

6.7.5: Imagination

Another aspect of liminality that was observed during the empirical stage of my study was the use of imaginative strategies. It is difficult to see how this fits into a transformative account of liminal learning. Mezirow (2009, 95) states that the

‘imagination of how things could be otherwise is central to the initiation of the transformative process.’ However, despite its centrality, there is very little concerning imagination in threshold concept scholarship; the word does not appear in the indexes of the four core texts nor in the subject index of the Flanagan bibliography. In the wider literature, Heath (2008, 115 - 117) points out that ‘little work has been done on what constitutes this capacity for the imagination’; it is not even precisely defined.

On the other hand Larrain (2017, 522 – 528) actually uses the phrase ‘active exploration’ when discussing how a listener makes sense of what another person is saying; she suggests that they use Peircean ‘abductive inferences based on the work of imagination’. Her context is outside the scope of this study; however Finke *et al.* (1996, 114), in a study of creative problem-solving, seem to equate imagination with what I have called active exploration: ‘imagination involves the generation and experience of ideas and products that go beyond what is currently known.’

The active exploratory learning interpretation suggests that a learner adjusts the structure of their prior knowledge and considers whether it reduces the perceived mismatch which initiated the liminal experience. But given that the prior knowledge has been successful up to that point it is likely that an adjustment may introduce inconsistencies making the knowledge weaker than it has hitherto been. As Driver (1983, 45) points out, ‘this may involve an imaginative act to consider the possibility of the new idea without necessarily believing it to begin with’. Some of my respondents employed strategies which actively considered situations which they knew to be incorrect, even to be impossible. This suggests that a role for liminality

might be the provision of a safe space where modifications to knowledge can be tolerated while they are being developed. Lakatos (1970, 143) proposes something similar when considering the process of theory adjustment in the history of science. Because any embryonic theory is likely to contain not-yet-resolved inconsistencies, in order to prematurely reject it 'it may be rational to put the inconsistency into some temporary, ad hoc quarantine' while seeking to further develop the theory. This in turn may link with the protective belt of auxiliary hypotheses that characterises a research programme; however, it is not the hypotheses itself that protect the liminal safe space but the idea of hypothesis: that what is being considered within liminality is conjectural and therefore temporarily protected from requirements of consistency.

Land (2006, 100) champions the imagination drawing on Milton, Blake, and Philip Pullman to contrast the 'creativity, energy and imagination of …Satan' with the 'highly ordered but somewhat dead and oppressive space' belonging to the angels. I have disputed the association of liminality with suffering and torment but if it is to be compared to a pandemonium it seems appropriate to recognise the opportunities for creativity and imagination that this affords.

6.7.6: Revising the expectation of distress

Reinterpreting the liminal experience as one of active exploration may help explain another surprising empirical finding of this study: that there was no evidence of distress in any of the respondents. The reaction to a challenge was often to smile. Although one respondent stated that he smiled because 'I was just ... compensating for myself looking like an idiot' he was still smiling when he said that. He and every

other respondent save one was prepared to volunteer for a second interview. Most respondents appeared to enjoy the challenge.

This was unexpected. The literature characterises liminality as unpleasant, painful, confusing, and alienating (see section 2.5.5). I found no evidence of the 'drop in morale' or the experience analogous to crisis which concerned Atherton (1999); no hint of the 'experience of exile and pain' of Mudge (2014, 55); no suggestion of the 'tension, anxiety, moments of uncertainty, and the disconfirmation of expectations' of Hansen and Laverty (2010, 226). Cousin (2008, 263 - 264) suggests that 'mastery of threshold concepts involves unavoidable learner anxiety' but my learners did not seem anxious. Atherton *et al.* (2014) suggest that liminality can 'amplify the fragility of the student and to increase the likelihood of failure and dropout' but only one of my respondents responded negatively to the offer of a second interview.

The most obvious explanation for this discrepancy is that my sampling method led to a skewed distribution. My respondents were all volunteers. Perhaps it was only those of high prior achievement who volunteered: Zohar and Aharon-Kravetsky (2005, 847) discovered that a cognitive challenge teaching method benefited high prior achievement students but hindered low prior achievement students. However, the studies that suggest liminality is unpleasant are usually conducted with university undergraduates; one would expect them to be of higher average ability than my sample since my respondents were pre-university students some of whom might fail to qualify for university. Perhaps the sample was skewed because only 'high-hope' learners volunteered; Snyder *et al.* (2002, 822 - 824) suggests that 'high-hope students' break goals into sub-goals and use these to track their progress, and 'find

multiple pathways to reach their goals and willingly try new approaches'; this last characteristic seems important in moving from treading water to boggy ground stuckness although it might actually make boggy ground stuckness more difficult. Perhaps my sample contained only resilient learners: Claxton (2002, 19) emphasises that powerful learners are resilient; Davidson *et al.* (2012, 334 - 336) suggest that resilience is predicted by learners who persevere; who believe that 'things happen for a reason' and 'can be managed'; and who believe that 'individuals can make positive outcomes occur through their own planning and personal initiative.'

Alternatively, it may be that the non-challenging environment of this inquiry, designed to encourage respondents to think aloud, enabled respondents to struggle without feeling distressed: Allen (2014, 33) suggests that 'if the process of entering liminality is deliberate, 'jumping' rather than 'falling' or 'being pushed' ... the unknown space that was scary becomes something that is able to be inhabited without disaster'. Csikszentmihalyi (1990, 74 - 75) suggests that matching the level of challenge to the level of skill will minimise the chance for either anxiety or boredom for the learner. Perhaps the challenge in this study just happened to be perfectly matched to the level of skill of the learners, although given the likelihood of some variation in the learner skill level this seems unlikely.

On the other hand the interpretation of liminality as a period of active exploratory learning suggests another reason why my respondents might not have felt distress. Timmermans (2010, 12) likens the liminal space to standing on the edge of a cliff: 'might not some learners feel terror, while others feel exhilaration?' Many writers

see the curiosity engendered by a cognitive challenge as intrinsically motivating. Thus St Augustine of Hippo proclaims that ‘we learn better in a free spirit of curiosity than under fear and compulsion’ (Augustine 1979) and Isaac Watts (1741, 1821, 271) said that ‘curiosity is a useful spring of knowledge’. More recently Bruner (1966) describes curiosity as ‘almost a prototype of the intrinsic motive’ suggesting that ‘such activity is biologically relevant, for curiosity is essential to the survival not only of the individual but of the species’. Some suggest that it is the joy of discovery that acts as a pull motivation driving us to explore. Thus Jeffrey and Woods (2009, 105) state that ‘breakthroughs feature strong emotion, which engages the whole person in the learning activity, rouses passion and sensitises the mind. There could be no more powerful motivation to learn.’ D'Mello and Graesser (2012, 145) recognise that ‘flow, delight, excitement, and eureka are experienced when tasks are completed, challenges are conquered, insights are unveiled, and major discoveries are made’. Gopnik (1998) compares the joy of the ‘eureka’ moment to orgasm suggesting that just as orgasm encourages humans to have sex so the breakthrough delight incentivises exploration.

If active exploratory learning is satisfying, either in itself or because it leads to a satisfying outcome, it goes some way towards explaining why my respondents were not distressed by their experiences. It can also help to explain why exploratory behaviour is common. Berlyne (1960, 104) states that ‘locomotor exploration appears to be universal among higher vertebrates.’ He also reports that human children practise ‘what-if’ investigations from the age of eleven months, ‘contriving changes in antecedent conditions to identify the associated changes in consequent events’ (Berlyne 1960, 157). Gopnik (1998, 107) points out that ‘the degree to which

infants and children actively and spontaneously explore the world is almost a cliché of parenting; we talk about how toddlers ‘get into everything’ or how preschoolers are always asking ‘why?’’ Spitzer (2006, 48) observed two-year-olds ‘actively try to understand their environment by examining it with little tests’.

6.7.7: Comparing the two interpretations

Two forms of interpreting the liminal experience have been discussed. Both interpretations can be located within the constructivist learning tradition. In particular, in both cases the liminal experience has been seen as being initiated by a cognitive challenge, and the analysis has been done assuming that the liminal experience is a solitary journey.

There is a difference in perspective. Learning as transformation has a teacher-centric perspective and primarily sees the learner as passive. It is essentially descriptive of the liminal experience which it sees as having characteristics such as stuckness (which can be subdivided into brick wall and boggy ground stuckness), oscillation and mimicry. There is little explanation of, for example, why a learner should oscillate across a threshold. Explanations for characteristics such as stuckness and mimicry often involve a learner-deficit approach. On the other hand, learning as active exploration, as the name implies, sees the learner as taking an active role, iteratively generating reorganised knowledge structures and considering what they imply. This perspective provides an explanation for oscillation and for the differences observed between ‘possible breakthrough ideas’ and ‘eureka’ events. It

reconceptualises brick wall stuckness as treading water stuckness and thus enables the two forms of stuckness to be reintegrated.

Finally I would argue that reflective self-dialogue, present in all but one of the responses in my study, is evidence for the active nature of the experience of liminality. The consideration phase of the active exploration model is reflective in the sense that the learner is considering their own knowledge as they have modified it. This demands a sort of fragmentation of the mind into two parts, viewer and viewed. It is speculated that this might be one of the functions of reflective self-dialogue.

It is important to maintain the learning as transformation interpretation because it is important to retain a teacher perspective on pedagogy. However, it has been shown above that active exploratory learning explains the empirical data better than the transformation interpretation; it also has much in common with the literature, particularly the ideas of Driver and Illeris. In the next chapter I shall set aside the transformation interpretation and explore the implications of this new interpretation of the liminal experience. This is a move from a perception of liminality as a time during which a transition takes place which is ‘often problematic, troubling, and frequently involves the humbling of the participant’ (Meyer and Land 2005, 376) to an understanding of liminality as ‘a provisional, exploratory space’ (Land *et al.* 2014b).

Chapter 7: Conclusions and Recommendations

7.1 Answering the research questions

7.1.1: What are the characteristics of learning transformation?

In the analysis of the empirical data collected, moments of potential transformation were coded as ‘possible breakthrough ideas’. The characteristics of these were compared against the characteristics of ‘eureka’ ideas found in the literature.

	‘Eureka’ moments	‘Possible breakthrough ideas’
Timescale	Within about fifteen seconds	
Accompanying emotion	Pleasure	Excitement, sometimes pleasure
Traceability of provenance	Unprovenanced	About half have traceable provenances
Does respondent feel certain that the idea is correct?	Yes	Sometimes but not always

Table 12: Comparison of ‘eureka’ moments with ‘possible breakthrough ideas’

However, since asking this question the liminal experience has been reinterpreted in terms as learning as active exploration rather than transformation. Under this interpretation the liminal experience is characterised by the learner repeatedly

modifying the organisation of their knowledge until they deem that the cognitive challenge that initiated liminality has been sufficiently resolved. This analysis suggests that the characteristics of ‘possible breakthrough ideas’ are typical of learning transformations and that the differences in terms of traceability of provenance are caused by the conceptual distance between the understanding before the transformation and that afterwards.

7.1.2: What are the characteristics of liminality?

Learners entered liminality after perceiving a cognitive challenge. Many of the respondents deliberately used problem-solving strategies. Evidence for reflective self-dialogue was found in all transcripts but one: this appeared to be a fundamental characteristic of the liminal experience.

A number of characteristics of liminality were elicited when the transcripts were coded using a transformation interpretation of learning. These were two types of stuckness (brick wall and boggy ground), oscillation and mimicry, and ‘possible breakthrough ideas’. However, an alternative analysis suggested that all these could be envisioned as aspects of learning as active exploration. This interpretation used a learner -centric perspective to relabel brick wall stuckness as treading water stuckness and to see both oscillation and mimicry as teacher-view descriptions of active exploratory learning.

7.1.3: How does a learner enter liminality?

The literature review suggested that the liminal experience would be initiated by a cognitive challenge; the empirical phase of this study was designed accordingly. Since the data collected suggested that a liminal experience had indeed been initiated this was taken as confirmation that a learner enters the liminal experience as a result of a cognitive challenge. However, analysis of apparent cases of threshold avoidance revealed that it was important to see the cognitive challenge from the point of view of the learner: although the challenge appeared to be about Newton's Laws of Motion it could also be seen as deriving from a mismatch between types of explanation.

Learners typically entered liminality with a period of stuckness. This was characterised as brick wall stuckness by the transformative interpretation which saw it as mental paralysis. However, an alternative interpretation suggested that the process of active exploratory learning was still continuing during these long pauses.

7.1.4: What is the relationship between transformation, liminality and learning?

The reinterpretation of the liminal experience as a time during which transformative learning took place to a period of active exploratory learning renders this research question problematic. Under this recharacterisation, all learning can be regarded as transformative because the encounter with new knowledge prompts the leaner to modify the organisation of their existing knowledge. Instead of answering this research question, this study has led to a reconceptualisation so that rather than

seeking a causal relationship between characteristics of liminality and transformative learning I have developed an exploration of alternative interpretations.

7.1.5: How can knowledge and understanding of the relationship between transformation, liminality and learning improve the teaching of secondary school physics?

Because I have set aside the learning as transformation within liminality interpretation this question is no longer appropriate. Instead I will reframe it to ask how knowledge and understanding of liminality as a period of active exploratory learning can improve the teaching of secondary school physics and whether the relationship between the teacher perspective of learning as transformation and the learner experience of learning as active exploratory learning can be reconciled in practice. This will be addressed in the next section.

7.2: How can the active exploratory learning interpretation of liminality improve the teaching secondary school physics?

The development of the active exploration interpretation of liminal learning as a core category in this study generates some suggestions as to how teachers might adapt their teaching. I am focussing on secondary school physics for this section firstly because it is the context of this study and secondly because it is the context in which I am most experienced. Nevertheless, I would expect that some of the suggestions might be generalisable beyond this immediate context.

Not all of the recommendations in this section stem from the core category. One of the advantages of the grounded theory approach is that it provides a more nuanced description of a study by capturing data and developing categories some of which may lay outside the core category. In this study these are represented by the recommendations regarding teaching explanations and teaching strategies.

7.2.1: Teaching strategies which make use of active exploratory learning

Despite the fact that they encountered difficulties and sometimes struggled to address the challenge, none of the respondents in this study showed any signs of distress when experiencing liminality. All but one volunteered to participate in a second challenge. This is an unusual finding. Most of the literature describes liminality in negative terms; there is an expectation that getting stuck is an unpleasant experience. On the other hand it was proposed in section 6.7.6 that active exploratory learning is satisfying, either in itself or because it leads to a satisfying outcome.

It has already been suggested (section 6.7.6) that my finding was due to sampling issues or that my challenge just happened to strike the right balance of challenge and anxiety to promote Csikszentmihalyian flow. These explanations postulate serendipities which are unlikely to be replicated in the classroom. An alternate explanation might take into account the context of the research. Whereas normal classroom teaching has a single teacher and multiple learners, in these interviews the learner was on their own. This had several implications. Firstly, the pauses were allowed to continue for longer than would normally be the case in a class. It may be

that active exploratory learning requires long pauses; it was suggested in section 6.7.4 that longer pauses allowed the learner to search further afield. This could be replicated in classrooms if a teacher asking a question required the whole class to refrain from answering for a certain length of time. This need not be a time of silence. Since active exploratory learning requires the learner considering their self-made modifications to their own learning it seems likely that this might be facilitated by some form of internal dialogue; this may be the rationale for the discovery of reflective self-dialogue. In section 6.4 it was suggested that the reason why children stop talking to themselves out loud when solving problems was due to social pressures and that a reverse Vygotsky manoeuvre might facilitate problem-solving. Therefore it is suggested that when a teacher asks a question or issues a challenge to a whole class, active exploratory learning would be facilitated if the learners were required to pause before answering and were permitted to whisper or mutter to themselves during this pause.

A second implication of the one to one nature of this study was that the respondents had nowhere to hide. It has been suggested that the sort of pausing found in treading water stuckness might have a strategic use for learners in a classroom situation; it might enable them to avoid answering the question because after a while the teacher will bounce the question to someone else. But I would have expected this to have increased the pressure on the respondents. After a while the pauses could become quite uncomfortable. One would expect this to increase anxiety which might interfere with learning. On the other hand the respondents might have felt more at ease because they were not pausing and becoming stuck in front of their peers. Since one to one learning is impractical in many classroom situations, is there

a way of reducing the social pressure that comes with the rest of the class waiting while you pause? One way in which this might be achieved is by hiding the learners from one another so that they can struggle anonymously. Although anonymity may be difficult to achieve in a traditional classroom the illusion of anonymity seems to characterise some online discourse. There is scope for research to see whether students experiencing liminality in an online environment, such as a discussion board or a second life seminar, especially one in which their identity is pseudonymous, have different affective experiences to students experiencing liminality in a traditional classroom.

Perhaps the difference was that I was trying to put them at their ease. An anecdote from my teaching career may help to explain what I mean. When I complained to one of my classes that they were wonderful to teach on Thursday mornings but dreadful on Friday afternoons one pupil retorted that I was really uptight on Friday afternoons. I expected a struggle and encountered one. I redeveloped my plans in an attempt to make the last lesson of the week an enjoyable experience for all, developing activities that offered opportunities for exploration. Rather than attempting to lead and direct the class I changed my teacher role to one of support and encouragement. An informal evaluation suggested that, although more was still learned during the Thursday lessons, more learning was occurring on Fridays than had been before the change in style. This resonated with the literature of the effects of anxiety in learning, for example Wang *et al.* 2015. It may be that liminal learning is facilitated by a low-anxiety teaching.

In the case of my Friday afternoon class, I deliberately left my teaching plans flexible so that what was learned was to some extent determined by the pupils. This was another aspect of the interviews in this study. Although there was a stimulus to drive the exploration there was no prescribed endpoint. Most teachers are constrained by the need for their learners to learn prescribed content and skills so that they have to shape and manipulate the learning into set directions. During these interviews I had the luxury of being able to follow my learners. This hints at a reconciliation between the idea that active exploratory learning driven by curiosity is motivating and the finding of most studies that the liminal experience is unpleasant. The teacher of threshold concepts doesn't want their students to explore a liminal landscape; they want them to pass through the chosen portal. It is the teacher who disdains learning other than that which the teacher intended as 'inauthentic' and 'mimicry'. Perhaps it is also the teacher who is intolerant of the delays imposed by stuckness.

It was stated above (section 6.7.2) that a transformation interpretation sees mimicry as a learner avoiding transformation either deliberately or as a result of a failure on their part. Such an interpretation suggests pedagogical strategies focusing on the learner. For example, we might teach resilience so that they are prepared to struggle for longer or we might institute ways of identifying those who are failing to give them help. Alternately we might use a selection strategy to filter out those students we deem likely to resort to mimicry before teaching them. The active exploratory learning interpretation sees mimicry as the inevitable consequence of learner exploration not necessarily providing the results desired by the teachers. This will lead to a focus on the teacher to develop strategies in which the learner can be free to explore while the teacher guides them towards the desired outcomes. There are

some pedagogies, such as project-based learning, in which it is the learner who is predominantly in charge of the direction of study. However, in most educational situations there are things that have to be learned. It is therefore necessary that the pedagogy makes a compromise with the curriculum. There are several ways in which this can be achieved.

Firstly, the challenging stimulus should be chosen with care. The ‘dog on the bed’ scenario had evolved from a previous ‘man on a floor’ scenario which I had used earlier in my teaching career because the fact that most of my learners knew that beds contained springs and sagged slightly when one stood on them assisted some of them to resolve the challenge. Following the success of the M12’s first person frame by frame strategy, next time I might abandon the dog and get learners to imagine themselves on the bed. When selecting the challenge one must be sensitive to how it will be perceived by the learners. This study suggested that the threshold avoidance found in other studies might not indicate that the learners were reluctant to engage with the challenge; two of the cases of potential threshold avoidance were dealt with by rephrasing the question. The alternative interpretation was that the learners had not perceived the challenge. This perception was reinforced when I realised that although I had intended the cognitive challenge to be focussed on Newton’s Third Law, most of my respondents were trying to solve a challenge based on a mismatch of explanations. Teachers must remember that the liminal landscapes around which they are trying to guide their students are internal to the students and therefore individual.

Secondly, the teacher should be ready to provide guidance along the journey. For example, I intervened during some of the interviews to remind respondents of an experiment they had recently performed on stretching springs. The guidance should be tailored to the needs of the learner, which means that the teacher has to be sensitive to those needs, listening to the individual learner or reading their work. This is rarely easy; when I transcribed the interviews I became aware that some of my interventions had been too early. Furthermore, the interventions must be proportionate: the aim is to get some students restarted and to guide others back towards a promising path. Finally, the interventions should be unobtrusive so that the learner stays in charge of the exploration.

Thirdly, the teacher should be ready to pounce on good ideas. In section 6.7.1 it was established that oscillation comes about because a learner does not necessarily know when they have articulated the breakthrough idea. A timely intervention at this moment might have enabled them to convert oscillation into eureka. During this study there were occasions when the respondent would advance an idea, pause and look at me. I interpreted this as an attempt to use my reaction to judge whether they were on the right track. For the purposes of this study I did my best to maintain a poker face. The teacher must take care over their interventions. How swiftly and how often guidance is given may affect the how effectively the ability to judge promisingness is learnt.

As the learner progresses from novice to expert it is to be hoped that their assessment of promisingness will improve. But it is probably not enough simply to repeatedly experience liminality; the same experience repeated may not lead to

progress. We need to enquire why experts are different from novices. Perhaps experts simply have greater confidence and are therefore prepared to pursue explorations for longer. Perhaps experts possess a greater repertoire; this might imply a need for case-based learning such as might be employed in law or medicine in which learners are presented with practice problems selected in order to highlight the features of both those scenarios which were successfully solved and those which were not. Alternatively, experts could offer witness testimony teaching. It has been pointed out (by, for example, Meyer and Land 2006a, 7 and Quinlan *et al.* 2013) that experts find it difficult to put themselves in the place of novices; nevertheless learners may find it useful if their teachers could reconstruct their own learning journeys, complete with barriers and how they overcame them.

An alternative teaching strategy might involve group work. Although it has been argued above (section 2.5.1) that liminality is experienced by individual learners, it cannot be denied that most learning takes place in a social context. Each individual learner might articulate their ideas and judge their promisingness by the reaction of the other members of the group. It is difficult to predict whether the learner would develop the ability to assess promisingness for themselves or would instead learn which ideas were more likely to find favour with the group. Perhaps the teacher might use regular reorganisation of the groupings in order to avoid the latter scenario.

Promisingness is an essential part of creativity. As suggested in section 6.5, most authorities believe that the skills required for promisingness can be learned through experience. However, when creativity is taught in schools the emphasis can be on

generating ideas; creativity is sometimes assessed by counting how many uses one can suggest for a paperclip. But the identification of boggy ground stuckness in my study suggested that my respondents had little difficulty in generating ideas; what was missing was their ability to recognise which ideas had promise. As suggested in section 6.7, it is therefore recommended that, when teaching creativity in schools, idea selection is foregrounded as a balance against idea generation. Care should be taken that an overly critical approach does not stifle ideas at birth. One method might be to encourage learners to rate ideas for promisingness and to articulate reasons for their rating. In the early stages of learning how to assess ideas this might be separated from the generation of ideas, even though the expert might see the generation of an idea and the assessment of its promisingness as integrated processes.

7.2.2: Teaching explanations

As established in section 6.1, the cognitive challenge that initiated liminality in this study was the perception that the explanation available to the respondent was not the explanation that was required. This led me to analyse the types of explanation that were attempted by my respondents and to compare my observations with systems of categorising explanations produced by other writers. I also produced a tentative hierarchy of explanations based on the observation that my respondents tended to prefer some explanations over others.

A discussion of the different types of explanation might help learners become aware of the different types. A number of my respondents struggled with the scientific concept of a ‘Law’ which they linked with ideas of ‘obeying’ or ‘abiding by’ which are

inappropriate for non-sentient objects. The respondent who recognised that Newton's Third Law expressed an observed regularity rather than dictated what must happen clearly found this realisation revelatory. This suggested that science teachers should make 'Laws' and other types of explanation more explicit. If learners were aware of the different sorts of explanation they might be able to structure their search for an alternative explanation; they might at least know the characteristics of what they were looking for.

At the same time they might become aware of the potential circularity of explanations. For example, once you have established that the mechanism by which a mattress provides a reaction force is down to its springs you then have to explain how a spring provides a reaction force; the explanatory chain can take you into increasing abstraction and yet at some point end with an explanation by decree: 'because that's what electrons do.' Such a nesting of explanations might discourage some learners; on the other hand the realisation that there will always be further levels to be drilled down into might challenge and motivate those learners who might one day become the experts driving back the boundaries of knowledge.

7.2.3: Teaching problem solving strategies

In section 6.7.2 it was proposed that teachers should not avoid using challenges to provoke liminal experiences in learners. It is probable that repeated experience of liminality will enable learners to develop strategies which will enable them both to cope with liminality better, to learn more from it and to learn from it faster. However,

we should not expect learners to develop effective strategies by themselves any more than we expect to teach people to swim by repeatedly throwing them into water. Instead, we should deliberately teach them strategies to navigate liminality productively.

Many of the problem solving strategies displayed in this study were employed by only one or perhaps two respondents. The evidence base for a discussion of which strategies were effective and which were not is therefore very weak and further research is needed before recommendations can be made with confidence. At this stage, therefore, the suggestions below must be regarded as tentative.

The problem of evaluating the promisingness of a proposed solution (discussed in the next section) meant that the respondent who employed the ‘Edison’ strategy of systematically listing everything she could think of sometimes failed to recognise potential answers, travelled from time to time in circles and overall took the longest of all the respondents (although she was more successful than some). This suggests that problem solving heuristics that interpret creativity as the ability to generate many ideas are mistaken. It is better to teach learners to use the Edison strategy rather than not to teach any strategy but it should be emphasised that this strategy is most effective when the problem space is relatively well-defined.

As described in section 6.3.3, imaginative strategies, such as the White Queen and the Sherlock Holmes, were more effective in this study. These strategies involve imagining what is thought to be impossible so enlarging the problem space allowing

exploration of ideas outside those suggested by expectation. Teaching these strategies, coupled with the idea of *reductio ad absurdum* to weed out those ideas that are truly impossible, is recommended.

However, the most effective strategies observed in this study were those employing visualisation. In particular, the respondent who created a mental movie of the challenge in which he himself took part solved the problem quickly and successfully. It would therefore seem that teaching this strategy might improve learning through liminality.

Imagination appears to be important for navigating the liminal experience and, by extension, for learning. However, there appears to be a relatively small body of literature on imagination in learning. This might constitute an important area for further research.

7.3: Implications for threshold concepts scholarship

The literature search of this study developed an understanding of liminality as a period during which transformative learning took place. However, the empirical stage of this study suggested that an alternative interpretation of liminality as a period of active exploratory learning was better able to unify the characteristics of the liminal experience into a coherent integrity; it also directed attention towards the processes of learning. It is proposed that this view of liminality has the potential to develop threshold concepts scholarship as a Lakatosian research programme.

Active exploratory learning enabled an integrated understanding of liminality. By providing an explanation for the differences, it had the potential to unify the constructs of transformation, the ‘possible breakthrough ideas’ in the empirical data and the ‘eureka’ moments in the literature. It also acted as a core category within which the characteristics of liminality such as stuckness, oscillation, and mimicry could be subsumed.

Characterising liminal learning as active exploration also positions it within the context of constructivist learning theories. This enables the development of a theory of learning in which a learner first uses expectations engendered by their prior knowledge to select and modify new knowledge; they then compare their expectations against the modified new knowledge encountered; and finally use the mismatch to modify their prior knowledge. Liminality is initiated by the learner’s perception of the mismatch; active exploratory learning describes the process of modifying the prior knowledge. As discussed in section 1.2.2 by embedding this interpretation of liminality within a constructivist view of learning it becomes possible to use this wider field to engender new theories; this therefore conforms to one of the criteria for a Lakatosian research programme. This has already been done in this study with the use of, for example, concept change learning theory and studies into ‘eureka’ events and self-talk to inform this research. Furthermore, the theory itself helps to explain how theory change can happen; prior knowledge is modified in the liminal period in a way that is resonant to the way a new paradigm can be developed with a liminal zone offering the necessary protection from inconsistencies during the development phase.

Another contribution made by this study to threshold concept scholarship has been the development of core ideas that are clearer, more explicit and less equivocal. For example, this study has unified the discrepant interpretations of oscillation. During the literature review (chapter 2) the philosophical underpinnings of threshold concept were made explicit. Evidence gathered during the empirical phase of this study has been used to better describe the liminal experience. Characteristics of liminality such as stuckness, threshold avoidance, mimicry and oscillation have been clarified. The key idea of active exploratory learning, which was used instead of the idea of transformation, has been made clearer by placing it within an outline theoretical framework.

Active exploratory learning has not only integrated a number of observational characteristics of liminality into a single coherent whole but it has also proved able to integrate threshold concepts scholarship with concept change learning and ‘eureka’ studies as well as positioning it within constructivist theories of learning. Is it therefore itself a threshold concept for threshold concepts scholarship? It is certainly transformative. It has adopted an altered perspective to view learning from the learner’s perspective rather than the teacher’s. This altered perspective has transformed the understanding of stuckness, oscillation, mimicry and the transformative ‘possible breakthrough ideas’ themselves. In so doing it has led to a number of proposals for improving the teaching and learning of those topics that seem to offer learning challenges and provided a route for the development of threshold concepts as a theory of learning.

This interpretation of the liminal experience has been developed from within the threshold concept framework. Yet at the same time the analogy of a new learner joining a class is applicable to each of the four types of learning, cumulative, assimilative, accommodative and transformative. For example, there will be occasions when the new learner will be placed with a group and no further reorganisation of the class will be necessary; nevertheless the overall structure of the class has been changed by the addition of the new learner. This is the analogy for cumulative learning. The other types of learning represent situations in which increasing reorganisation becomes necessary following the addition of the new learner. This implies that threshold concept learning may not be separate in terms of the learning processes involved but rather be distinctive by virtue of involving a more complex reorganisation or prior knowledge than the other forms of learning. This then leads to the question of whether the liminal experience is unique to threshold concept learning or whether all learning involves liminality to a greater or lesser extent. It might be asked whether, for example, reflective self-dialogue is only found during liminal learning or whether the frequency of reflective self-dialogue is indicative of the depth of liminality.

It was suggested above (section 6.7.3) that the longer pauses of treading water stuckness might be indicative of the conceptual distance that the learner has to travel to resolve the cognitive challenge; this was also linked to the ability of the learner to identify the provenance of a possible breakthrough idea. These ideas are also linked to the question of whether or not liminality is a distinctive characteristic of threshold concept learning or whether it is present to a different degree in all types of learning. These questions might be resolved by a study comparing the think aloud

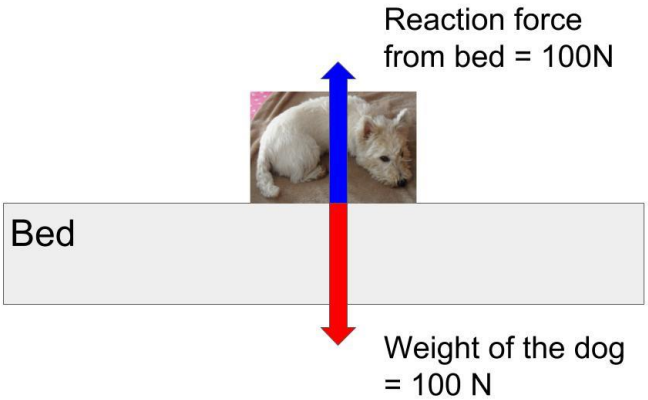
behaviour of learners faced with threshold concept cognitive challenges against learners encountering with non-threshold concept learning.

Schwartzman (2010) calls for the development of a theoretical foundation for threshold concepts, suggesting that to do so one must focus on the journey of the learner through the liminal experience to discover ‘how learning happens’ rather than ‘what it means to have learned’; one must clarify terminology and one must explore ‘how students actually do respond’ to challenge, rather than how they should. My study has attempted to follow this guidance. By developing a learner-centric interpretation of the liminal experience grounded in empirical evidence I have developed the foundations for a threshold concept learning theory which has the liminal experience at its heart. There are signs that threshold concept scholarship is beginning to look further than the identification of threshold concepts in the curriculum (Bhola and Parchoma 2016, Land *et al*. 2014b). I believe that such a realignment of threshold concept study would be beneficial and that this study represents a step in this direction.

There is still a great deal to understand about liminality but I hope that this study has begun to shine a light into what Land *et al.* (2016, xvii) called ‘the 'black box' of thresholds research’.

Appendix One: The dog on the bed stimuli

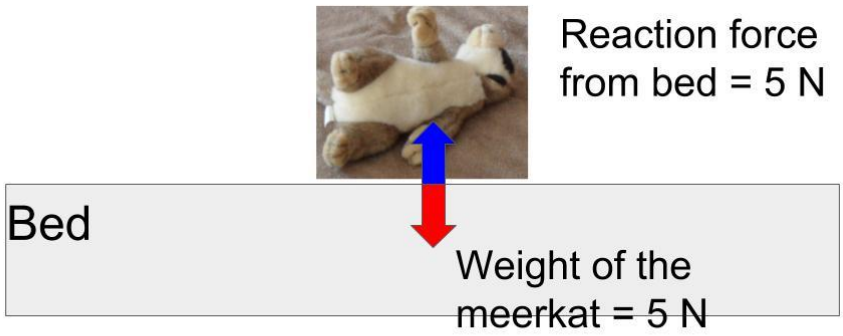
Stimulus #1



This slide was shown after the respondent had correctly solved the problem posed by stimulus #1.


The dog jumps off the bed and is replaced with a 5 N meerkat. What forces act on the meerkat?

Stimulus #2



This picture was shown after the respondent had correctly solved the problem posed by stimulus #2.

Stimulus #3.

Appendix Two Ethics

Initial ethics submission

SECTION A To be completed by the candidate

Registration No: 1417163

Candidate: Dave Appleby

Degree of: MPhil leading to PhD

Research Institute: IRED

Research Topic: What makes Threshold Concepts difficult to learn? Exploring liminality.

External Funding: None

The candidate is required to summarise in the box below the ethical issues involved in the research proposal and how they will be addressed. In any proposal involving human participants the following should be provided:

- clear explanation of how informed consent will be obtained,
- how will confidentiality and anonymity be observed,

- how will the nature of the research, its purpose and the means of dissemination of the outcomes be communicated to participants,
- how personal data will be stored and secured
- if participants are being placed under any form of stress (physical or mental) identify what steps are being taken to minimise risk

If protocols are being used that have already received University Research Ethics Committee (UREC) ethical approval then please specify. Roles of any collaborating institutions should be clearly identified. Reference should be made to the appropriate professional body code of practice.

General ethical issues:

There are no conflicts of interest. The researcher no longer works for a school. Participation of the school where he worked will not be sought.

There are no health and safety issues.

Publication: Neither participants nor schools will be identified in any published work except anonymously. Where a participant is quoted, permission shall be sought in advance from the participant.

This is an observational study rather than an intervention study. However the techniques used of focused interviews and Think Aloud protocols might encourage the participant to reflect upon their own learning. This might nudge the participant towards a learning style that advantages the participant over learners not selected for the study. Alternatively the

participant might develop anxieties over their learning. These possible effects will be minimised by the experimenter quickly sharing results and tentative implications with the individual participants and their teachers; if the results seem positive the teachers will thus be provided with an opportunity to extend the techniques to all learners in the educational setting.

Certainty Based Marked True False test of a participant's understanding

- Ethical issues: This might involve some participants below the age of 18. Some participants may experience some distress at being tested on their knowledge and understanding of Physics. Participation will be voluntary and anonymous.
- Informed consent will be obtained by;
    - Seeking written recorded informed consent from the headteacher of the school (or their delegated representative)
    - Seeking written recorded informed consent from each participant
- Individual data will be anonymised by assigning each participant a unique code number. The researcher will be the only person who keeps a record showing the link between the code number and your name. At the end of the research this record will be destroyed. The interviews will be recorded and transcribed by the researcher; after the transcriptions the recordings will be destroyed. The written data

will be stored in a password protected computer file using https security. Before any individualised data is quoted in the final research report any quoted participant will be contacted to ensure that they are happy with the quote; the quote will be anonymised.

- At the end of the research, a brief outline of the research findings will be made available to all participants.
- Should a participant so request, the session will be terminated immediately and the data accumulated in tat session discarded. This will be made clear to participants in the letter seeking informed consent.

Learning journey interviews

- Ethical issues: This might involve some participants below the age of 18. Some participants may experience some distress at being asked about their knowledge and understanding of Physics. Participation will be voluntary and anonymous.
- Informed consent will be obtained by;
    - Seeking written recorded informed consent from the headteacher of the school (or their delegated representative)
    - Seeking written recorded informed consent from each participant
- Individual data will be anonymised by assigning each participant a unique code number. The researcher will be the only person who keeps a record showing the link between the code number and your

name. At the end of the research this record will be destroyed. The interviews will be recorded and transcribed by the researcher; after the transcriptions the recordings will be destroyed. The written data will be stored in a password protected computer file using https security. Before any individualised data is quoted in the final research report any quoted participant will be contacted to ensure that they are happy with the quote; the quote will be anonymised.

- At the end of the research, a brief outline of the research findings will be made available to all participants.
- Should a participant so request, the session will be terminated immediately and the data accumulated in tat session discarded. This will be made clear to participants in the letter seeking informed consent.

Answer the following question by deleting as appropriate:

1. Does the study involve vulnerable participants or those unable to give informed consent (e.g. children, people with learning disabilities, your own students)?

   Yes; as well as adults some young people aged between 16 - 18 will be asked to participate in questionnaires, tests and one-to-one interviews. Given that the research aims to discover what makes some concepts difficult to learn it is thought important to include the perspective of the learners themselves.

   If **YES**: Have/will Researchers be DBS checked?

   Yes; most recent enhanced disclosure number 001361795077 issued 26th April 2012 in context of working as Ofsted Inspector

2. Will the study require permission of a gatekeeper for access to participants (e.g. schools, self-help groups, residential homes)?

Yes; research to take place in schools; headteachers will be asked to give consent; in addition each participant will be asked for consent.

3. Will it be necessary for participants to be involved without consent (e.g. covert observation in non-public places)? **No**

4. Will the study involve sensitive topics (e.g. sexual activity, substance abuse)?

No

5. Will blood or tissue samples be taken from participants?

No

6. Will the research involve intrusive interventions (e.g. drugs, hypnosis, physical exercise)?

No

7. Will financial or other inducements be offered to participants (except reasonable expenses)?

No

8. Will the research investigate any aspect of illegal activity?

No

9. Will participants be stressed beyond what is normal for them?

No

10. Will the study involve participants from the NHS (e.g. patients) or participants who fall under the requirements of the Mental Capacity Act 2005?

No

If you have answered yes to any of the above questions or if you consider that there are other significant ethical issues then details should be included in your summary above. If you have answered yes to Question 1 then a clear justification for the importance of the research must be provided.

*Please note if the answer to Question 10 is yes then the proposal should be submitted through **NHS research ethics approval procedures** to the appropriate **NRES**. The UREC should be informed of the outcome.

Checklist of documents which should be included:

Project proposal (with details of methodology) & source of funding	yes; self funded
Documentation seeking informed consent (if appropriate)	one version for headteachers, one version for participants
Information sheet for participants (if appropriate)	na
Questionnaire (if appropriate)	see project proposal

(Tick as appropriate)

Revised ethics submission

Research Ethics Scrutiny (Annex to RS1 form)

SECTION A To be completed by the candidate

Registration No: 1417163

Candidate: Dave Appleby

Degree of: PhD

Research Institute: IRED

Research Topic: Threshold Concepts: Exploring Liminality

External Funding: None

The candidate is required to summarise in the box below the ethical issues involved in the research proposal and how they will be addressed. In any proposal involving human participants the following should be provided:

- clear explanation of how informed consent will be obtained,
- how will confidentiality and anonymity be observed,
- how will the nature of the research, its purpose and the means of dissemination of the outcomes be communicated to participants,
- how personal data will be stored and secured
- if participants are being placed under any form of stress (physical or mental) identify what steps are being taken to minimise risk

If protocols are being used that have already received University Research Ethics Committee (UREC) ethical approval then please specify. Roles of any collaborating institutions should be clearly identified. Reference should be made to the appropriate professional body code of practice.

How informed consent will be obtained

By a letter to each gatekeeper (headteacher/ principal) together with a meeting so that any questions may be answered.

Outline agreement has already been obtained from The Bedford Sixth Form Centre and Kimberley College.

The Bedford Sixth Form Centre teaches mostly A-level courses to 16 - 19 year olds In Bedford. It is affiliated with Bedford FE College. The participants will be recruited from the AS Physics class.There has been an initial meeting with the Headteacher, Assistant Headteacher and Head of Physics. Further meetings with the teaching staff and with the AS Physics students will follow should this proposal be agreed.

Kimberley College is a 16 - 19 STEM college based in Stewartby, Bedfordshire. It opened in September 2013 as part of the Wootton Academy Trust.The participants will be recrutied from the three AS Physics classes. There has been an initial meeting with the Head of Physics and further meetings with the prospective participants will follow should this proposal be agreed.

Each learner participant will also be informed by letter. Where appropriate, this letter will also seek the informed consent of the parents of participants.

How confidentiality and anonymity will be observed

All of the responses will be kept confidential. The data will be anonymised by assigning a code number. The researcher will be the only person who keeps a record showing the link between the code number and the participant's name. At the end of the research this record will be destroyed. The interviews will be videoed, recorded and transcribed by the researcher; after the transcriptions the videos and recordings will be destroyed. The written data will be stored in a password protected computer file using https security (see below) The school will not be identified in the final report.

How the nature of the research, its purpose and the means of dissemination of the outcomes will be communicated to participants,

Through letter seeking informed consent

How personal data will be stored and secured

The data will be anonymised by assigning a code number. The researcher will be the only person who keeps a record showing the link between the code number and the participant's name. At the end of the research this record will be destroyed. The interviews will be recorded and transcribed by the researcher; after the transcriptions the recordings will be destroyed. Any physical copy made of the written data will be stored in a locked cabinet in the EST office at the Department for Teacher Education in the University. Online copies of the data (digital audio, video and images, data collected in online environments and data converted into digital formats) will be pseudonymised as above at the point of data entry, stored in a password protected computer file in a web-based software using https security; once analysis is complete this data will be downloaded onto the secure disk-based system maintained by the University of Bedfordshire.

Steps being taken to minimise risk participant stress

Participants will be debriefed at the end of each session. They will also receive individualised, interim, draft summaries of any relevant findings from the research. A

potential source of stress for participants is a lowering of confidence in their ability to learn; this will be monitored carefully by the experimenter and if there are signs of this happening a range of strategies from reassurance to termination of the participation will be implemented. Non-participants may feel disadvantaged. Everyone studying the subject as the school/ college will be offered the chance to participate. Any summary, interim, draft hints or tips, suitably anonymised, regarding how learning might be improved will be made available to non-participants

Answer the following question by deleting as appropriate:

1. Does the study involve vulnerable participants or those unable to give informed consent (e.g. children, people with learning disabilities, your own students)?

   Yes; young people aged between 16 - 18 will be asked to participate in lesson observations, problem solving activities and one-to-one interviews. The study investigates liminality for learners of this age group.

   If **YES**: Have/will Researchers be DBS checked?

   Yes; most recent enhanced disclosure number 001361795077 issued 26th April 2012 in context of working as Ofsted Inspector

2. Will the study require permission of a gatekeeper for access to participants (e.g. schools, self-help groups, residential homes)?

   Yes; headteachers

3. Will it be necessary for participants to be involved without consent (e.g. covert observation in non-public places)? **No**

4. Will the study involve sensitive topics (e.g. sexual activity, substance abuse)?

No

5. Will blood or tissue samples be taken from participants?

No

6. Will the research involve intrusive interventions (e.g. drugs, hypnosis, physical exercise)?

No

7. Will financial or other inducements be offered to participants (except reasonable expenses)?

Yes; learner participants will be offered tuition as a thank you for the time spent on the study; this to happen following the data collection phase and not to be in any way contingent upon nature of participation

8. Will the research investigate any aspect of illegal activity?

No

9. Will participants be stressed beyond what is normal for them?

No

10. Will the study involve participants from the NHS (e.g. patients) or participants who fall under the requirements of the Mental Capacity Act 2005?

No

If you have answered yes to any of the above questions or if you consider that there are other significant ethical issues then details should be included in your summary above. If you have answered yes to Question 1 then a clear justification for the importance of the research must be provided.

*Please note if the answer to Question 10 is yes then the proposal should be submitted through **NHS research ethics approval procedures** to the appropriate **NRES**. The UREC should be informed of the outcome.

Checklist of documents which should be included:

Project proposal (with details of methodology) & source of funding	see below
Documentation seeking informed consent (if appropriate)	see below; one letter for gatekeeper, one letter for teacher participant, one letter for learner participant
Information sheet for participants (if appropriate)	On document seeking informed consent
Questionnaire (if appropriate)	

(Tick as appropriate)

Outline Project Proposal

Definitions of liminality:

- ‘a suspended state in which students can sometimes struggle to cope’ (Land *et al.* 2014; p1; conference proceedings)
- the 'discomfort zone' (Mudge 2014; p 62)

In this project I will investigate liminality/ aporia among learners of A-level Physics by:

- Classroom observations
- One to one interviews with teachers
- One to one interviews with learners
- Setting challenges designed to put learners into the liminal space and asking learners to solve them whilst talking aloud

Responses will be analysed in terms of a three-fold framework:

(Burbules 2000; p 179)

- No path in sight
- Confusion: too many paths; can't choose
- A path in sight but don't want to travel it for fear of lurking (ontological?) monsters

Questions which might be asked of the data include:

- Is liminality purely an affective experience or does it have an epistemological or ontological dimension? Are there ways of minimising the pain of liminality?
- Where are the frontiers of the liminal space?
- Are there different routes through liminality? Are some paths better than others?
- Is liminality avoidable?
- Is liminality essential to learning?

- Does the negotiation of liminal space require a teacher? What sort of teaching can achieve maximum benefit from minimum pain when traversing the liminal space?

Letter to headteacher

Dear Headteacher/ Principal,

I am carrying out research with the University of Bedfordshire into Liminality which is that feeling of stuckness some learners experience during conceptual change. I am focussing on A-level Physics. If the research is successful it may help to improve the teaching of this subject.

I am seeking your help in this research.

I would like to recruit some of your A-level Physics students and some of their teachers to participate.

No participant will take part in this research unless and until they have individually given their informed consent.

The research activities in which students might be involved are:

- Lesson observations to observe liminality in context
- Thinking aloud whilst solving problems and challenges in Physics
- An interview to explore how you get stuck and how you unstick yourself

The research activities in which teachers might be involved are:

- One to one interviews to discuss how they guide learners through liminality
- to observe liminality in context

Every participant would have the right to withdraw from the research at any time they chose.

Some of these activities would need to be carried out on a confidential one-to-one basis although the participant would have the right to have another person in the room. As the researcher I have enhanced disclosure number 001361795077 issued on 26th April 2012, a copy of which is available on request.

All of the responses will be kept confidential. The data will be anonymised by assigning a code number. The researcher will be the only person who keeps a record showing the link between the code number and the participant's name. At the end of the research this record will be destroyed. The interviews will be videoed, recorded and transcribed by the researcher; after the transcriptions the recordings will be destroyed. The written data will be stored in a password protected computer file using https security. Your school will not be identified in the final report.

At the end of the research, a brief outline of the research findings will be made available to all participants and to your school.

Please let me know if there are any potential participants I should not approach, perhaps because you feel they are unable to give informed consent, or for any other reason.

This research has been approved by the University of Bedfordshire Research Ethics Committee.

Please contact the researcher on daja57@gmail.com if you have any questions.

I am willing that the research outlined above should take place in my school subject to the safeguards above and subject to extra conditions and restrictions as written below.

Signed

Dated

On behalf of

Letter to participant

Dear participant,

I am carrying out research into how learners get ‘stuck’ when learning A-level Physics. If the research is successful it may help to improve the teaching of this subject.

I am seeking your help in this research.

The research activities in which you might be involved are:

- Lesson observations to observe liminality in context
- Thinking aloud whilst solving problems and challenges in Physics
- An interview to explore how you get stuck and how you unstick yourself

You have the right to withdraw from the research at any time you choose.

All of your responses will be kept confidential. Your data will be anonymised by assigning a code number. The researcher will be the only person who keeps a record showing the link between the code number and your name. At the end of the research this record will be destroyed. The interviews will be videoed, recorded and transcribed by the researcher; after the transcriptions the recordings will be destroyed. The written data will be stored in a password protected computer file using https security. Before any individualised data is quoted in the final research report you will be contacted to ensure that you are happy with the quote; the quote will be anonymised.

At the end of the research, a brief outline of the research findings will be made available to all participants.

This research has been approved by the University of Bedfordshire Research Ethics Committee.

Please contact the researcher on daja57@gmail.com if you have any questions.

I am willing to take part in the research outlined above subject to the safeguards above and subject to extra conditions and restrictions as written below.

Signed

Dated

On behalf of

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